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ABSTRACT

This study was designed to describe teachers' and students' conceptions of biology and biological knowledge. The conceptions were revealed through observations of classroom events, individual discussions, and interpretations of verbal communications recorded during classroom presentations and were described in terms of significant positions in a philosophy of biology. Three biology teachers and eighteen students participated in this qualitative study. The participants' conceptions of biology were analyzed and the individuals were grouped according to the philosophy of biology they most frequently exhibited. The three teachers were perceived as exhibiting a modified positivistic position. Conclusions reached in the study indicate biology is conceived by the majority of the participants in a positivistivc manner. The teachers conceive of it in this way and their lesson presentations reinforce their conceptions. Students generally adopt a conception of biology that agrees with the teachers' views. (ML)

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TEACHERS' AND STUDENTS' UNDERSTANDINGS OF BIOLOGY

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Garth D. Benson

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SECONDARY EDUCATION

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(Signed): G Benson

PERMANENT ADDRESS:

Box 301
Bragg Creek, Alberta
T0L 0K0

Dated: April 16, 1984

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Teachers' and students' understandings of biology", submitted by Garth D. Benson in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Secondary Education.

K. G. Jacknicke
Supervisor

Wytze Brouwer

Harry Garfinkle

Douglas A. Roberts
External Examiner

Date April 19/84

ABSTRACT

This study attempts to reveal and describe teachers' and students' understandings of biology. The attempt to reveal the participants' understandings was accomplished by examining their conceptions of biology. Their conceptions were revealed through observations of classroom events, individual discussions the researcher held with the participants and interpretations of verbal communications recorded during classroom presentations. The participants' conceptions were described in terms of significant positions in a philosophy of biology.

The conceptual framework of the study was seen as a series of principles that have a reciprocal arrangement with the study. The principles directed the research just as the research influenced the framework. The principles included premises from the sociology of knowledge, hermeneutics and the philosophy of biology.

A review of science education research indicated that methodologies employed in quantitative studies did not allow questions to be examined from various philosophical positions. Recently the development of qualitative techniques has created a form of research that permits questions to be examined from a variety of philosophical positions.

A qualitative approach was used in the study. Three biology teachers and eighteen students participated in the study. The research methodology consisted of observing and recording on audio cassettes the three teachers' lessons on nutrition. Individual, informal discussions were held with each of the three teachers and eighteen students. The informal discussions were also recorded. Complete transcriptions were made of each informal discussion and the lessons of one teacher. Partial transcriptions were made of the lessons of the other two teachers. Written interpretations of the participants' conceptions were made and returned to the individuals for validation.

An analysis scheme based on Esland (1971) and Werner (1978) was developed. The participants' conceptions of biology were analyzed according to the framework and the individuals were grouped according to the philosophy of biology they most frequently exhibited. The three teachers were perceived as exhibiting a modified positivistic position. The eighteen students were divided into three groups. Seven students exhibited a modified Baconian image of biology, three students exhibited a modified positivistic image and three students exhibited a conceptual change view. Five students chose not to provide a second validation and their conceptions were not analyzed.

Conclusions reached in the study indicate biology is conceived by the majority of the participants in a positivistic manner. The teachers conceive of it in this way and their lesson presentations reinforce their conceptions. Students generally adopt a conception of biology that agrees with the teachers' views. In three cases, students exhibited views that suggest contemporary philosophical thought.

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CHAPTER I

INTRODUCTION TO THE STUDY

Introduction

Traditionally biology is viewed as a science that is rational, objective and concerned with explanation of natural phenomena. In conjunction with this view there is an understanding that biological knowledge consists of observable information derived from controlled experiments. The purpose of establishing such information is to provide explanations so that accurate predictions can be made and nature can be controlled. This view of biology is largely based on Francis Bacon's view of the scientific method. Although Bacon had little influence over his contemporaries (Dampier, 1971, p. 126), the "Baconian method" has directly influenced science education. A variety of textbooks, including Modern Biology (Otto and Towle, 1977, p. 5-6) outline a slightly modified Baconian method and state, "The steps in this research method are logical and orderly. In fact they are simply a system of common sense."

A Baconian view of science education is commonly presented to students but it is only one way of viewing biology and it is suggested that such a view excludes many attributes of science. For example, intuitive elements of artisanship are excluded from the discipline.

This study is an attempt to examine biology teachers' and students' conceptions of biological knowledge and biology and as a result disclose their notion of high school biology.

Purpose of the study

Frequently, biology textbooks include a section that deals directly with the author's conception of biology or his conception is blended into material included in the preface, introduction or beginning chapters. The textbooks that are authorized by Alberta Education as primary resources for Biology 30 offer particular interpretations of biology (Kimball, 1974; McElroy and Swanson, 1968). For example, McElroy and Swanson portray biology as a method of understanding the natural world so that predictions can be made. Implicit in their meaning of the word "understand" is an element of control where man has power over nature. This point is clearly stated when they say, "Understanding is also a means to power. That is, power to control and use our environment to our advantage." (1968, p. 122). In contrast, Kimball presents biology as being complex and difficult to understand but possessing a beauty beyond description. Although Kimball has introduced an aesthetic element, he is consistent with McElroy and Swanson's view of science as a way of controlling nature because he states "with new knowledge comes new power" (1974, p. xvii).

In addition to curriculum materials presenting a particular view of biology, teachers of the discipline also project a view of the subject when they present subject matter to students. While considerable research has been done on the development of a wide range of science curricula, little attention has been paid to the underlying views of science projected by those curricula. Besides a lack of research on the underlying views of disciplines associated with the curricular projects, little work has been done on teachers' conceptions of science or how their conceptions colour the presentation of material to students.

This study attempts to reveal and describe conceptions of biology and biological knowledge that teachers and students of biology hold. Their conceptions are revealed through observations of classroom events, individual discussions the researcher held with the participants and interpretations of verbal communications recorded during classroom presentations. The participants' conceptions of biology are then described in terms of significant positions in a philosophy of biology. An element of the study is to relate the participants' conceptions of biology with their view of knowledge and with that as a grounding attempt to describe their conceptions of biological knowledge.

The study should provide the participants an opportunity to reflect on their view of biology and biological knowledge because of their involvement in the research process. Hopefully, the study will also reveal a variety of conceptions of biology and provide educators with a clarification of an existing situation which may act as a basis for subsequent research questions.

Focus of the study

The focus of the study is an exploration of the conceptions of biological knowledge that are held by teachers and students of biology as well as their conceptions of biology as a discipline. A particular effort is made to examine the teachers' conceptions and how they are reflected in classroom presentations. Once the participants' conceptions are examined a synthesis of the observations, analyses and interpretations is made. The synthesis of this material brings out the major points of the teachers' and students' conceptions. The meaning that is obtained from the synthesis is examined in terms of positioning the participants' conceptions within a philosophy of biology.

Methodological approach to the study

The situational study

One assumption of the present study is that individuals interpret biology from their own personal orientations. This point is discussed in detail in Chapter II when the theoretical framework of the dissertation is considered.

Given that participants react to the study from various perspectives it is necessary to position the study within an appropriate methodology. In Knowledge and Human Interests, Habermas (1971) conducts a critique of the conceptions of science which may be found in the writings of philosophers and practitioners of science up to that time. He attempts to show that there is no single model of science but rather several forms of scientific inquiry. Each form of science is governed by man's particular interests. These interests are basic to man and characteristics associated with such interests are connected to specific dimensions of the social world. On this basis Habermas concludes that scientific knowledge is not a pure and value-free product of an objective methodology, but it is linked by man's interests to the reproductive processes of social life. The three forms of scientific activity are termed "empirical-analytic science", "historical-hermeneutic science", and the "critical social sciences" (1971, pp. 308-315). Associated with these Habermasian forms of science are three basic orientations of man's interests. Each orientation determines the type of activities to be pursued as well as the form of knowledge that is warranted. The structure Habermas developed allows us to question knowledge that individuals hold and the assumptions on which such knowledge is based.

Aoki (1978) expanded the Habermasian framework so that it is applicable to curriculum research. He adapted Habermas's forms and expanded them into three orientations which act as metaphors that "help us to disclose approaches to curriculum development, curriculum evaluation and curriculum research (p. 2)."

The dominant orientation within our society is termed empirical-analytic where the primary interest lies in establishing predictive control in technical situations. The second orientation is termed historical-hermeneutic where the primary interest is associated with the understanding of meaning attributed to situations by individuals

The third orientation is termed critical-theoretic in which emancipation and concern for the human condition is most important. Implicit with the third orientation is a demand for action which improves the human condition.

Empirical-analytic orientation

The empirical-analytic orientation is one in which man views the world in a technological way. Major values of this perspective are control, certainty, predictability and efficiency (Werner, 1978, p. 7). Individuals who adopt this orientation view themselves as applying a method through which they control events. In effect, they are separating man from the world and viewing the world as an object. A key factor in their world perspective is the existence of immutable laws which allows man to identify cause and effect relationships. It is through such relationships that their conception of control becomes possible (Thompson and Held, 1982, p. 7).

Objectivity plays a major role in this orientation because knowledge that is considered neutral is seen as certain. Knowledge which is based on controlled experiment is viewed as being objective because an individual has isolated variables and tested the apparent effect of each factor. Because individuals have confidence in the method, they attribute the characteristic of certainty to value-free knowledge and they accept such knowledge as true.

The concept of objectivity is dependent upon the separation of man and the world. By viewing himself as separate from the world it is possible to conceive of an independent natural world. When man investigates natural phenomena his conception of objectivity excludes his social interests and knowledge produced by those social interests.

Situational orientation

A fundamental assumption of the situational orientation is that man gives meaning to situations in which he finds himself. Associated with the concept of assigning meaning is the idea that individuals act with intentionality (Wagner, 1970, p. 318). An intentional act is any act through which a person experiences an object. It is through such intentional acts that individuals establish meanings because once an object is experienced the object itself is cognitively constituted. Man is seen as being part of the world instead of being separate from it because he gives meaning to his situation. With man and his world being one, there is a reciprocal influence in any action.

The values of this orientation are the relevance and meaning associated with particular situations. Since the practical interest of interpretation is intersubjective understanding, man's efforts are directed to determining and clarifying the meanings of situations. With reality being considered as socially constructed, knowledge is not viewed as an object; instead it is viewed as part of an individual because it is dependent on the history of the world as well as the individual's personal experiences. Knowledge is not a reality; it varies from person to person.

Critical-theoretic orientation

A basic assumption of the critical-theoretic orientation is that man's perspective of the world is shaped by personal experiences and the world's history. Any personal action is inevitably biased because everyone brings a viewpoint to a situation. A critical orientation is concerned with examining the underlying values and assumptions associated with perspectives in order to reveal and clarify the basis of action. The questioning of underlying values and assumptions is referred to as critical reflection and its purpose is to disclose and make explicit the framework and foundation of actions.

Implicit within this orientation is the idea that critical theory leads to change. Critical theory provides a basis for change because alternatives are suggested when a foundation is questioned at the level of values and assumptions. To assist in the generation of alternatives Werner (1978, p. 19) identifies a series of questions that may be considered when a critical approach is adopted. For example, when a perspective is being disclosed questions concerning the underlying interests, assumptions and approaches of that perspective should be raised.

Context of the study

The present study is seen as partially belonging to both the situational and critical orientations. The situational orientation is adopted because a segment of the study involves an investigation of meanings of teachers' and students' conceptions of biology and biological knowledge. As such the study attempts to disclose meanings associated with various conceptions. Part of making the interpretations of the teachers' and students' conceptions is an analysis which raises questions of the perspectives of man and knowledge, social relations between teachers and students, as well as the control of communication. By raising such questions the study is adopting a reflective stance which reveals the framework and foundation of a particular situation. Consequently, the study is not purely situational nor critical-reflective.

A review of science education literature indicates empirical-analytical interpretations of science have been a concern for a long time (Hurd, 1970, 1975; Kessen, 1964; Kimball, 1968; Mackay, 1971; Mead and Metraux, 1957). These studies are in the empirical-analytic mode of educational research where control, certainty, efficiency, precision, predictablility and standardization are predominate values. The studies were aimed at identifying and overcoming deficiencies of students and teachers. An implicit assumption of these studies is that researchers' perceptions of deficiencies are accurate and by explaining the causes of such deficiencies appropriate techniques will be developed to overcome them. This dissertation is dissimilar to the analytical studies in that it attempts to understand participants' conceptions of biology and the significance such conceptions have for the study of biology. Because the intents and the mode of research chosen for the study are different than those of the studies cited, the criteria on which knowledge claims are to be judged are also different. Criteria concerning validity, reliability and generalizability are interpreted in the following way.

Validity

Validity in qualitative studies is interpreted to be "the adequacy of a description as a representation of a social situation" (Dawson, 1979, p. 1). Since the adequacy of a description involves various purposes, the validity of knowledge claims must be viewed from a framework that recognizes the relationships among these factors. Statements concerning validity must be viewed as whether or not the descriptions provided accurately reflect and interpret the participants' meanings. Dawson indicates several ways to establish validity, but the major method is to ensure that participants confirm or disconfirm the researcher's descriptions and interpretations of the situations. Psathas (1973) also offers tests of validity for qualitative studies. The first test is similar to Dawson's in that it asks whether descriptions and interpretations accurately reflect the participants' meanings. The other tests are more applicable to ethnographic studies where a culture is being investigated, and they are not considered here.

Reliability

Reliability, as it is used in empirical studies, involves the concept of measuring accurately and consistently from one situation to another (Best, 1977; Travers, 1969). The present study uses the concept of reliability in a different sense compared to Best and Travers, yet there is a common feature to both interpretations. Since this study is based in a situational mode, empirical reliability is inappropriate because quantitative measurements are not being taken. Reliability in terms of this study is understood to mean that descriptions and interpretations accurately and consistently reflect the situations as the participants experience them. It is in this way that reliability is closely connected to validity. In other words, if the data, descriptions or interpretations are valid they must be reliable.

Generalizability

Generalizability as used in this study is interpreted in Denton (1974, p. 112) and Stephens's (1982, p. 78) manner in which features of a specific situation are abstracted and then linked to general considerations. The study does not attempt to use generalizability as it is interpreted in terms of sampling theory. The concept of generalizability is to be understood as whether the reader can extract themes from participants' interpretations of biology so that the reader makes sense of his particular situation. In Denton's words, if there is movement from general to particular and back again generalization has taken place.

Research methodology

The study began with the identification of a research question which arose from examining the thesis put forward by T. Kuhn (1962) in _The Structure of Scientific Revolutions._ His argument suggests that biology as it is presented to students is a misinterpretation of what the discipline has been, what it is and what it is capable of doing.

The research question took the form of, What are the conceptions of biology and biological knowledge that are held by teachers and students of biology? Once a research question was formulated planning was undertaken to allow the researcher entry into a research situation.

As a situational study depends upon the cooperation of the participants, preparation for entry into a situation must be carefully planned. The following discussion will focus on the pre-entry, entry, and follow-up procedures employed in the research.

Pilot study pre-entry

A literature search revealed that previous studies related to individuals' conceptions of science employed a technical orientation. Such an orientation was perceived by the researcher as a limitation. The studies are discussed in Chapter III. To avoid having students and teachers react to the researcher's conception of biology it was decided to adopt a situational research framework. Once a situational framework was adopted it became necessary to determine the feasibility of such an approach in terms of the research question.

The researcher approached a university faculty member and briefly explained the proposed research to determine if the faculty member was aware of biology teachers who might consider being involved in a research project. Four individuals were suggested. The first teacher contacted expressed interest in the study and agreed to participate if the study was acceptable to the administrators of the school.

Planning for the pilot study began and it was decided the purpose was to determine:

(1) what are appropriate questions that reveal teacher and students' conceptions of biology;

(2) if classroom events influence students' conceptions of biology;

(3) what views of biology are currently held by the participants of the study;

(4) if the participants are able to identify factors that influence their conceptions of biology.

It was planned that the researcher would observe classroom lessons during the time subsection 2 (Nutrition) of the Biology 30 curriculum was taught. This section was purposely chosen as some information dealing with autotrophic and heterotrophic nutrition is not clearly understood by biologists. The authorized textbooks indicate some information concerning nutrition is either presently unexplainable or explained by conflicting theories (Kimball, 1974, pp. 289-292; McElroy and Swanson, 1968, pp. 498-500). It was anticipated this section of the curriculum would provide the teacher an opportunity to present biology as a discipline which deals with tentative knowledge. An opportunity would also exist for the teacher to present a number of conflicting theories and thereby illustrate creative aspects of biology. For example, elements of personal commitment, nonrationality, intuition or imagination could be demonstrated through the presentation of conflicting theories. The reason the study was done with Biology 30 students is that the researcher assumed older students would be more aware of their conceptions of biology and biological knowledge and they also would be more readily aware of factors that influenced the development of their conceptions.

The teacher who agreed to cooperate, spoke to the principal of the school to determine if a research project would interfere with the school's operation during a two-week period in late October or early November. The principal of the school indicated a research project would be acceptable if conducted at that time. The researcher submitted an official application to the Edmonton Public School System on September 29, 1982, to perform a pilot study. Official approval for the pilot study was received October 6, 1982 and the researcher contacted both the teacher and principal to arrange a time to discuss the rationale and the techniques of the proposed research. Because the research focused on a specific portion of the Biology 30 curriculum, an agreement was made between the researcher and teacher to begin the project November 8, 1982.

The pilot research was to take place in two phases. First, the procedure was to record the teacher's classroom presentations concerning nutrition on audio cassettes and, at the completion of the lessons, record a discussion dealing with the teacher's conception of biology. It was planned that an interpretation of this material would be made and returned to the teacher for validation. The validation procedure was to discuss the interpretation with the teacher to determine if it accurately reflects the situation as well as his conception. Once the teacher had commented on the interpretation it was to be re-written and submitted for a second validation.

The second phase consisted of attempting to establish students' conceptions of biology. It was planned that the members of the class would be approached by the researcher at the end of the first week's observations to request six students to volunteer to discuss their conceptions of biology with the researcher. The discussions were planned to last approximately fifteen minutes, be done on an individual basis or in groups of two, and be conducted during the students' spare periods. The discussions were to be open-ended but based on a set of questions similar to those included in Appendix A. The questions were designed to reflect the content matter of the lessons that were presented at the time of the individual discussions. The validation procedure for the students was similar to the one previously described for the teacher. The only difference was that they were to be prepared as soon after the discussion as possible.

Pilot study entry

A situational study is dependent upon the researcher being accepted and trusted by the participants. If acceptance and trust are lacking on the participants' part, it is doubtful a study similar to the proposed research would be possible. In an effort to establish a feeling of trust it was planned the teacher would discuss with the students the researcher's arrival prior to the beginning of the observations. It was also planned that at the beginning of the first period in which classroom observations were to be made, the researcher would explain the reasons for his presence, the type of research that was being conducted and how the students could be involved in the study. It was a purposeful decision not to ask for six student volunteers at this point but to wait for one week and allow the students to become familiar with the researcher's presence.

Upon arrival for the first classroom period involving observations, it was discovered the cooperating teacher was absent and a substitute teacher was unaware of the research project. Students showed some curiosity as to why the researcher was in the classroom. Two students asked the researcher why he was there and after a brief explanation one of them said "O.K., I know who you are."

At the beginning of the second week of observations students were asked to volunteer to discuss their conceptions of biology with the researcher. Six students agreed to volunteer after hearing a brief explanation of the types of questions that would be involved in the discussions and the validation procedure. Arrangements for suitable times for the discussions were made at the conclusion of the class. The informal discussions were recorded and the researcher prepared initial interpretations of the students' conceptions of biology. Of the six students who originally volunteered, one chose not to participate.

Pilot study validation

At the completion of the classroom observations the cooperating teacher was hospitalized and the validation of the interpretations of classroom lessons was not carried out.

Shortly after a student discussion took place the researcher listened to the recording, prepared an initial interpretation of the student's conception of biology and then gave the interpretation to the student for comment. The students were instructed to make comments on points they agreed with, disagreed with or did not understand. The researcher indicated he would discuss these points with the student. The students briefly read the interpretation and agreed with the written statement. Based upon the students' comments, corrections and alterations were made to the interpretations wherever necessary.

An examination of the pilot study data revealed that an informal discussion using open-ended questions disclosed participants' conceptions of biology and biological knowledge. It was also discovered that students associate their conceptions of biology with current classroom events, as well as earlier science courses. It was observed that the students read the interpretations quickly and then agreed with the comments. Two inferences are contained in this observation. One, the interpretations were superficial and they repeated the students' comments instead of making an interpretation. The second inference is the students were not given adequate instructions and they did not understand the purpose of having them validate the interpretations.

Research pre-entry

As the research project developed it was decided it should be expanded from one teacher and six students to three teachers and eighteen students. The reason for expanding the study was to gain a broader view of individuals' conceptions of biology and biological knowledge. At this time a question arose as to whether observing the lessons of three classrooms plus interpreting eighteen student discussions plus three teacher discussions was excessive in terms of a time commitment. Despite some misgivings about the amount of time involved in the expanded study the researcher decided to proceed.

As in the pilot study, a university faculty member was approached for a list of biology teachers who he thought would be receptive to participating in a research study. Early in January 1983 thirteen teachers were contacted and the nature of the study was explained. A Science Department Head of a large composite high school stated he would approach staff members to determine if they were interested in participating in such a study. Approximately a week later the department head provided names of three Biology 30 teachers who volunteered. On the basis of information received from the pilot study plus the three volunteer teachers, a request was made to the Edmonton Public School System on January 19, 1983 for permission to conduct an enlarged study. The study was to involve eighteen students plus three teachers from three Biology 30 classes. Approval was received January 31, 1983 for the study to proceed.

Once again the department head was contacted and he arranged to introduce the participating teachers to the researcher. During the discussions with the three teachers the rationale and the methodology of the study was explained. Agreement was reached when the observations would begin.

Overview of the research method

The dissertation is considered a situational study because it examines a group of individuals in a particular situation (Werner and Rothe, 1980). The phenomena of revealing meanings associated with individuals' conceptions and the implications such meanings have for knowledge, are not directly observable, therefore a variety of ethnographic techniques are employed. For example, discussions based on open-ended questions, observations, participant observations and transcripts of lessons are employed in the study. These techniques are adopted because they have the potential of uncovering meanings associated with individuals' conceptions.

The planned research method was for the researcher to act as an unobtrusive observer for the first week of classes and make observations of classroom events as well as record, on audio cassettes, lessons presented by the teachers. The intent of this position was to minimize interruptions in classroom events. The first week was seen as an adjustment period in which a working relationship of acceptance and trust was developed. At the beginning of the second week the researcher's role was to become one of an observer-participant because a request was to be made for six students of each class to volunteer to discuss their conceptions of biology and biological knowledge with the researcher. The observer-participant role was to continue until the completion of the study.

The validation of student discussions was to overlap with data gathering. The researcher anticipated a discussion would be held with a student and a written interpretation of the discussion would be made later in the day. The interpretation would be given to the student at the next class and a request would be made of the student to review the interpretation critically. The purpose of the critical review was to ensure the researcher did not misrepresent the situation nor the student's conception of biology or biological knowledge. Once the student had reviewed the interpretation it was to be re-written on the basis of the student's comments.

The validation procedure for the three teachers differed because a transcription of their lessons was necessary for an interpretation to be made. Originally it was planned that a transcription of each teacher's lessons and discussion would be prepared. Once the transcriptions were prepared an interpretation of each teacher's conception of biology and biological knowledge would be made. A copy of the interpretation was to be sent to each teacher requesting they review it and mark points they agreed with, disagreed with, or did not understand. Based on their comments, corrections and alterations would be made to the interpretation wherever necessary.

An analysis scheme was purposely left undecided until after the transcriptions were examined for prominent themes. This decision was taken because a preconceived analysis scheme predetermines which data are considered important thus providing direction to the interpretations.

Research entry

At the meetings with the three teachers it was agreed observations would begin February 28, 1983 with teacher "C". The three teachers are labelled "A", "C", and "D". There is no teacher "B" as the researcher used the initial of his surname in the transcripts of teachers and students' discussions as well as those of classroom lessons. The starting times for making observations were staggered because the three teachers were at various points in the previous section of the course.

Teacher "C" began the nutrition section February 28, teacher "A" March 3, and teacher "D" March 8. The length of time each teacher devoted to the section varied. The number of sixty-four minute periods were thirteen, seventeen, and fourteen respectively and the researcher spent approximately four weeks, on a full-time basis with the three teachers and their students.

Prior to the start of the observation phase each teacher explained to their class a university researcher would be conducting a study during the time the nutrition section of the course was presented. The teachers also indicated to the students that the possibility existed for them to be involved in the study if they wished. At the beginning of the first class each teacher introduced the researcher and allowed him to explain the nature of the study. The researcher indicated to the students that in approximately a week a request would be made for six volunteers. It was explained that the six volunteers would discuss their conceptions of biology and biological knowledge with the researcher. The students were told each discussion would last approximately fifteen minutes and they would be done on an individual basis. Examples of the types of discussion questions were provided.

Observations

The observation phase consisted of two parts. The first part consisted of recording, on audio cassettes, the lessons presented by each teacher. The second part consisted of making notes about the lessons and observations made during the classroom visits. The notes consisted of observations concerning teaching styles, points that were excluded from the lessons, the manner in which the nature of biology was presented and perceived content errors. An observation sheet (Appendix B) was used to record the main features of the classroom/laboratory plus teaching strategies. General notes were made of relevant points observed during informal discussions which took place at coffee breaks and lunch hours.

Discussions with teachers

It was planned an informal discussion would be held with each teacher after each teacher's series of lessons was complete. The reason the discussions were planned after the lessons was that the context of many of the questions depended on the lesson material. The discussions were of an informal nature and they each lasted approximately one hour. The term "informal discussion" is defined in a manner similar to Rowell (1983, p. 20). She states an informal interview is "a conversational exchange between two people who are prepared to share the meanings of their experiences. The direction of the interview is guided by those experiences which the participants recognize as relevant to the inquiry. The interviewer does not select questions designed to elicit the specifics of a situation, but rather, questions which in revealing his "not-knowing" of the experience, invite the participant to disclose his interpretations."

Questions posed during the informal discussions focused on the individual teacher's view of biology as a discipline, their conception of biological knowledge, and their philosophy of science as it relates to biological knowledge. At the end of each discussion questions were raised about points observed during the series of lessons. For example, one teacher developed a mechanistic analogy to explain how scientific observations are considered proof for a theory or an hypothesis and the researcher questioned the teacher as to what constitutes scientific proof in terms of his conception of biology.

Discussions with students

The discussions with students were also of an informal nature. The questions that were used to initiate the discussions are based in the philosophy of science and the sociology of science (Appendix C).

The questions are based on a variety of works (Fay, 1975; Feyerabend, 1975, 1980; Harris, 1979; Kimball, 1968; Kuhn, 1962; Mulkay, 1979; Popper, 1962) and they were modified to suit particular discussions as well as the topic of nutrition. Although a framework existed to initiate discussions many questions arose from classroom events or students' comments and questions. In this way the discussions were a conversational exchange in which the direction was not predetermined.

Analysis of data

Teachers' analyses

A predetermined analysis scheme dictates the data that are examined. To avoid this limitation it was decided to make a transcription of each teacher's lessons and informal discussion and then examine the transcriptions for prominent themes. In terms of this study prominent themes are those that are repeated in the transcription or those that the teacher emphasized through communicative devices. The framework for establishing themes is repetition or emphasis and the researcher assumes those points that are repeated or emphasized are considered important by the teachers. A framework and an analysis scheme are different in that a framework is equivalent to a perspective while an analysis scheme is a method by which the prominent themes are examined.

Once teacher "A"'s themes were established one analysis scheme was developed. The analysis scheme consists of a series of guiding questions based on studies by Esland (1971) and Werner (1978). The guiding questions provide a focus which permits the researcher to examine a teacher's pedagogic and subject perspectives. As a result of examining a teacher's perspectives, interpretations are made of his conceptions of biology as a discipline and biological knowledge.

A copy of the interpretation was sent to teacher "A" and he was requested to examine it in light of points he agreed with, disagreed with, or did not understand. A time was arranged to discuss the interpretation with him. The discussion formed the first validation of the interpretation.

Once an interpretational framework was established it became possible to listen to the audio tapes and transcribe selected portions of lessons for teachers "C" and "D". The reason this was done was to reduce the massive number of hours required to obtain literal transcriptions in which some of the material is inconsequential. The informal discussions for both of these teachers were fully transcribed. The interpretation and validation procedure used for teacher "A" was followed for teachers "C" and "D".

Students' analyses

At the beginning of each discussion with a student the researcher explained the discussion would be recorded and reviewed later in the day. The researcher listened to each discussion and prepared a written interpretation of the major points related to the student's conceptions of biology and biological knowledge. The interpretation was given to the student the following day with instructions to provide the first validation of it.

A transcription of each student's discussion was prepared and examined in terms of the historical view of the philosophy of science as it is discussed in Chapter III. The purpose of examining the student's discussions was to describe their conception of biology in relation to established positions in the philosophy of science. The discussions were also examined for points which describe the student's conception of biological knowledge. An interpretation of the student's conceptions of biology and biological knowledge was made on the basis of the transcription of the discussion, and the validated interpretation. The eighteen interpretations were mailed to the students and arrangements were made to discuss the interpretations with them. Comments received during these discussions served as the basis for a second validation.

Validation procedures

Teachers' validations

At the conclusion of each teacher's informal discussion the researcher indicated that a transcription of the lessons and discussion would be made and they would provide the basis of an interpretation of the teacher's conceptions of biology and biological knowledge. It was also indicated that the interpretation would be mailed and the researcher would arrange a time to discuss the teacher's comments.

The first validation consisted of discussions in which the individual teachers and the researcher went over the interpretations point by point. Each discussion was approximately three to three and one-half hours in duration. During this time the teachers indicated points they agreed with, disagreed with or did not understand. They also provided insights into reasons for events included in the interpretations. They clarified their conceptions by explaining their views in terms of the philosophies of science and education. Based on each teacher's comments the interpretations were revised where necessary.

The second validation consisted of discussing the re-written interpretation with each teacher and once again re-writing it where necessary. The discussions for the second validation were approximately fifteen minutes in duration.

A third validation occurred for two of the teachers. After completion of the second validation the researcher again contacted two of the teachers to clarify specific issues that had arisen from re-examining the interpretations.

Students' validations

The student validations took place in two stages. The first stage consisted of explaining to each student the importance of reading the interpretation critically to see if the researcher represented their conceptions of biology and biological knowledge. The pilot study revealed students read the interpretations very quickly and did not raise many questions. To overcome this difficulty in the main study the researcher stressed the importance of providing comments about the interpretation. Also the researcher indicated that a statement may be included in the interpretation that the student had not said nor intended to say. One such statement was included in one student's interpretation and the student immediately identified the statement. In each case the student's comments were noted and included in the revised interpretations.

The second stage of the student validation consisted of sending the eighteen re-written interpretations to the students and arranging a time to discuss points related to the interpretations. Of the eighteen students, eight discussed the interpretations of their conceptions in person. The discussions typically lasted about forty-five minutes. Five students mailed comments and five students chose not to respond. On the basis of the comments received the interpretations of the conceptions of thirteen students were re-written.

Chapter I discusses the background to the study and identifies a methodology which places the dissertation in the situational and critical orientations. The discussion of the methodology describes the pre-entry, entry and validation procedures for both the pilot and main studies. The methodology consists of an observation phase during which teacher's lessons were recorded on audio cassettes and a discussion phase where individual informal discussions were held with three teachers and eighteen students. Transcriptions of the lessons and discussions formed the basis of interpretations of the participants conceptions of biology and biological knowledge. The interpretations were validated by discussing them with the participants and re-writing the interpretations where necessary.

CHAPTER II

CONCEPTUAL FRAMEWORK OF THE STUDY

Introduction

This chapter outlines the conceptual framework for the study. The framework is not to be considered a rigid structure which moulds the research methods or results, but is seen by the researcher as having a dialectical relationship between itself and the practicalities of the research. By outlining the conceptual framework the structure for the study is clarified and particular predispositions of the researcher are revealed to the reader.

Framework of the study

Alfred Schutz (1962, 1967, 1970) develops the premise that meanings that make up the common-sense world are based on experiences within that world. To examine the meanings of the common-sense world it is necessary to realize that meanings arise from interpreting experiences. Britton (1970, p. 12) summarized the essential point of Schutz's premise by stating, "we construct a representation of the world as we experience it, and from this representation, this cumulative record of our own past, we generate expectations concerning the future; expectations which, as moment by moment the future becomes the present, enable us to interpret the present." According to Schutz, if we do not realize that meanings arise from interpretations we accept our constructed reality as a given and never question it.

The theory of knowledge that is being suggested by Schutz is a view that knowledge is grounded in social existence. That is, as society changes so do our ideas, ideologies and values. Berger and Luckmann (1967) advanced a theory of the "social construction of reality" in which a basic premise is everything that passes for knowledge is socially based. One of the fundamental thoughts of their work is that the reality of specific groups is objectified in symbols that are communicated, such as art and language. The realities of these specific groups are spread throughout society and different groups hold to isolated meanings and values thus they interpret, or see, aspects of the world in different ways. Their study (1967, p. 3) excludes the classical sociology of knowledge, that was advanced by individuals such as Karl Mannheim, Max Scheler and Emile Durkheim, because classical knowledge was seen as ideas or what were termed the higher forms of knowledge. Since cultural knowledge is the basis of Berger and Luckmann's work, scientific knowledge is also excluded because the classical sociologists of knowledge argued that scientific knowledge was of a special form and not influenced by culture. Berger and Luckmann exclude scientific knowledge from their conception of the sociology of knowledge because they do not see history or present social conditions affecting it.

Recently, researchers in the sociology of knowledge have begun to argue for the inclusion of scientific knowledge in their discipline. Barnes (1974); Brannigan (1981); and Mulkay (1969, 1979) argue for the inclusion of scientific knowledge in sociology of knowledge because scientific knowledge does not possess special status and it is influenced by historical and cultural factors. Studies such as those done by Mendelsohn (1974, 1977) and Moulines (1981) support the contention that cultural factors influence the development of biological knowledge.

An assumption of the dissertation is that individuals participating in biology classes do so with intentionality. Meanings of situations are constructed through an individual's actions. The construction of meaning is part of the assumed, but unquestioned, reality that was previously mentioned. An individual's perspectives are also part of the taken-for-granted reality. Perspectives are developed partially by beliefs, intents and interests (Werner, 1977) and it is these frames of reference, or perspectives, that guide individuals in ordering their world. Since the construction of meaning is highly idiosyncratic an individual's perspective is peculiar to that person. It is on this basis that the participants in this study are expected to be making sense of biology from their own personal orientations. The concept of an individual's perspective provides a basis for the examination of meanings of biology and the resulting implications such meanings have for students' conceptions of biology and biological knowledge.

The concept of perspective

Alfred Schutz (1962, 1967, 1970) argues that meanings attributed to our common-sense world, or "world of daily life" are socially constructed. According to his thesis the intersubjective world existed prior to our birth and our interpretation of this existential world is based on a stock of previous experiences that forms the world's history, our personal experiences of that world, and interpretations passed to us by other individuals (Schutz and Luckmann, 1973, p. 7). The combination of these interpretations and experiences form the "knowledge at hand" and it functions as a frame of reference from which individuals act. A person's knowledge at hand serves as an organized way of interpreting past, present and future experiences.

A person's stock of knowledge has a structure which is determined by practical and theoretic interests and it is established according to relevance systems (Cox, 1978, p. 111). As an individual's interests determine his relevance system it is imposed by situational and social conditions. One of the qualities of a relevance system and an individual's stock of knowledge is that they are made of typifications. The process of typifying (Cox, 1978, p. 111) is the way in which meaning is given to an experience.

The concepts of types and typification create a reciprocal functioning of relevance systems and stocks of knowledge. The formation of types takes place within a context of relevance systems but the result is itself sedimented, or integrated, into previously acquired knowledge. Because a stock of knowledge is influenced by acquired knowledge, a relevance system and a stock of knowledge are reciprocally related.

According to Schutz an individual orients himself in the everyday world so that he makes sense of his situation. An individual's orientation is determined by elements of his subjective experiences which direct his focus and enable him to interpret his world. The elements of his subjective experiences that are chosen are guided by "in-order-to" and "because-of" motives (Schutz, 1970, p. 126). "In-order-to" motives refer to subjective experiences that determine his actions so that a goal is reached. "Because-of" motives refer to inducements from past experiences as an individual reflects on those experiences. The "in-order-to" and "because-of" motives provide a connection between systems of relevance and social action.

Part of the common-sense world consists of social interaction with members of various groups. The most concrete form of social interaction is that of communication (Cox, 1978, p. 112). Within the concept of communication is the idea that individuals' relevance systems have a degree of congruence. In group organization the degree to which individuals' perspectives and relevance systems overlap determine group membership. Individuals who have overlapping perspectives are considered members of an in-group (Schutz, 1970, p. 81) and because their system of knowledge is common, communication is readily accomplished. Members of in-groups accept the cultural pattern handed down as an unquestioned guide for interpreting the world. According to Schutz the function of such a cultural pattern is to provide a prefabricated method of establishing meaning. The connection between Schutz's argument and the present study is the participants are members of an in-group and their perspectives of biology become suitable for investigation.

One aspect of Schutz's analysis of the world of daily life is the origin of knowledge. As an individual's interpretation of the existential world depends on historicity, personal experience, and teachings, it is logically consistent that only a small part of an individual's knowledge originates in personal experience (Schutz, 1970, p. 96). The majority of knowledge is socially derived from "friends, parents, teachers and teachers of teachers." A fundamental point of the origin of knowledge is a person is taught how to define the typical features of the world prevailing for his in-group. Schutz's position indicates individuals' perspectives partially determine what is considered the stock of knowledge and since the majority of knowledge is derived from sources other than personal experience a question is posed as to the relationship of teachers' and students' conceptions of biology and biological knowledge.

In summary, the participants in a classroom are members of an in-group and common aspects of their cultural pattern are shaped by their interests and motives. When perspectives of the in-group's everyday world are considered, questions are raised which relate to conceptions of biology and biological knowledge.

The previous sections deal with levels of knowledge in the sociology of knowledge. The main ideas contained in those sections are: one, biological knowledge is socially constructed as are other forms of knowledge. This means biology teachers and students construct meanings for their common-sense worlds through their social actions. Two, teachers' and students' perspectives help order their common-sense worlds and part of their perspectives are a variety of conceptions of biology and biological knowledge. Three, the concept of perspective is addressed in Schutz's theory of knowledge in that individuals' stocks of knowledge contribute to their perspectives. Such stocks of knowledge are determined by individuals' relevance systems which are in turn determined by their motives. The "in-order-to" and "because-of" motives connect individuals' relevance systems to their social actions. Four, biology teachers and students are members of an in-group and part of social action is the act of communication. Therefore, by examining their conceptions of biology and biological knowledge that are communicated in classrooms, relationships among the conceptions should be seen. Because there is a connection between social action and perspective the act of examining individuals' conceptions clarifies the image of biology and biological knowledge in relation to the participants' common-sense worlds.

The concept of hermeneutics

Hermeneutics is the study of interpretation and understanding, especially the task of understanding texts (Palmer, 1969, p. 8). Palmer identifies six definitions of hermeneutics that range from biblical exegesis to the study of phenomenological existence with its associated meaning of existential understanding. The earlier forms of hermeneutics generally focused on methods and validity while more recent forms focus on meanings associated with understanding. Recent hermeneutical theory concerns itself with a principle that maintains interpretation is shaped by the question with which the interpreter approaches the text as well as the inherent meaning of the text itself. Within this principle are the two foci of hermeneutics: one, the interpretation of texts, and two a theory of understanding in a general sense.

Until recently hermeneutic theory was concerned with establishing the valid interpretation of a literary text. The theory considered the understanding of a text to be a psychological reconstruction (Hoy, 1978, p. 11). The idea of a reconstruction was necessary because the prevailing view of interpretation was that history was no longer immediately accessible and a reconstruction of the text was necessary to bridge the past to the present. A theory of this form continues to have force as evidenced by Hirsch's (1967) position. He presents a theory which includes criteria to validate interpretations. Hoy is critical of Hirsch's approach because the criteria are to be applied according to the author's intentions. Hirsch argues for an unchanging meaning as the goal of interpretation because it is believed that some interpretations are more correct than others. His position is based on the idea that there is an objective basis for interpretations (Palmer, 1969, p. 60). A limitation of Hirsch's position is that it is impossible to show an objective basis is either knowable or that it is ever captured in interpretations.

Hirsch claims that there is no objectivity in interpretation unless the meaning of the text is unchanging. He bases this inference on the premise that the author's intended meaning is determinate and reproducible (1967, p. 27). To him, understanding of a text is equivalent to constructing the text's meaning in its own terms and interpretation of the text is equivalent to explaining the text's meaning. The object of understanding and interpretation is the explanation of meaning, while the object of judgement and criticism is determination of the significance of the text.

According to Hoy (1978, p. 24) the theory of psychological reconstructionism argues that it is necessary to postulate one correct interpretation of the text so that validity is possible. The assertion of objectivity is used as a basis for maintaining the possibility of a valid interpretation. Hirsch connects the concept of validity to an author's intention and argues that if a text's meaning is validly explained the interpreter has correctly established the significance of the text. By arguing in this way Hirsch has connected validity and verification so that one depends on the other.

Hoy (1978, p. 33) points out validity and verification can be separated in that an interpretation, though correct, is still invalid because of fallacious arguments or the wrong reasons have been given for the interpretation. Validity is seen to be a condition where, once all the relevant evidence is taken into account, the interpretation is internally consistent. Verification is a concept where the interpretation is debatable in terms of its own evidence. Hoy's analysis suggests an alternate form of understanding interpretation is possible.

Gadamer (1975) offers a hermeneutic theory in which the nature of understanding is a result of clarifying the features of the text, the interpreter's understanding of the subject matter, and the interpreter's input. This input consists of the world's history which the interpreter shares, the tradition in which the interpreter stands, previous interpretations, and the contemporary state of hermeneutics. By introducing the concept of "Wirkungsgeschichte", or the awareness of standing within an operant history, (1975, p. 263) there is no longer a need to postulate a bridge between past and present experiences. Because participants share a common world of shared meanings, they share a language and this means interpretation involves the analysis of meanings shared through communication. The meaning of the text is seen as that which the interpreter gives to the text as well as an inherent meaning in the text. As the text poses a question to the interpreter he approaches it with a particular personal history and gives a meaning to it. Because the text is a construction of language it also has an inherent meaning itself and the interpreter tests his meaning against the text (Hoy, 1978, p. 67).

A perceived problem with the two forms of meaning is that they may be seen as relative. Gadamer counters the charge of relativism by claiming the process of communication involves a language which is more than a system of symbols. Part of the communication process is understanding. Since understanding involves both interpretation and application, relativism is avoided (1975, p. 405). Meanings of texts are contextually bound because interpretations are relative to the circumstances of the interpreter and the the text. As contexts are chosen by the interpreter, justification for the choice should be given. The choosing of a context means different lines of interpretation are possible. This does not mean all interpretations are equally plausible because not all contexts are justifiable.

Gadamer's contextualism is not arbitrary because the interpreter does not choose a pre-determined set of criteria to analyze a text. The interpretation arises from the interpreter's situation and the interpretative understanding is conditioned by such a situation as well as the text's context. The legitimacy of an interpretation is determined by examining the appropriateness of an interpreter's experiences and the context of the interpreted work.

The concept of understanding

Generally, when a person speaks of "understanding" they are using the term to mean explanation. There is a sense that such a view of understanding involves a methodology where connections are established. The intent of this dissertation is to use the term in a phenomenological and critical sense. Understanding is conceived in Gadamer's terms (1975, pp. 190-192, 230-232). To him, understanding is a concept in which the meaning of a situation is moving beyond being. The concept involves possibility; the possibility of interpreting; the possibility of seeing beyond connections. A traditional conception of understanding attempts to grasp the immediacy of an expression and does not look beyond. The intent of the descriptions of teachers' and students' conceptions of biology in this dissertation is to establish a communication between the text and the reader. The communication should disclose being a biology teacher and being a biology student. Understanding also involves critical sense making in that questions are raised about the underlying intents, motives and assumptions of biology teaching. Such questions add a dimension to the text's meaning and what it communicates with the reader.

In summary, this chapter discusses the theoretical basis on which the study is based. The conceptualizations of socially constructed knowledge, perspective and interpretation provide a structure to examine individuals' conceptions of biology and biological knowledge. The section on socially constructed reality indicates the discipline of biology concerns itself with knowledge that is constructed by man. Since history and personal experience determine an individual's perspective the presentation of biological knowledge becomes a problem of study because traditionally the discipline has been viewed objectively. Interpretations that are made of the participants' conceptions of biology and biological knowledge reflect a contextual viewpoint instead of a psychological reconstruction of meaning.

CHAPTER III

RESEARCH IN SCIENCE EDUCATION

Paradigms of science education research

Kuhn's (1962) concept of a paradigm had a dramatic impact on both the natural and social sciences. He suggested research in the natural sciences usually operates within a framework, or paradigm, of normal science. A paradigm is the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community (1970, p. 175). A paradigm directs the research questions, methodologies, data interpretation as well as determining acceptable standards of explanation. The normal science paradigm for the natural sciences is successful in that controlled situations are possible. Lowery (1980, p. 276) suggests empirical methods in normal science are successful because it is possible to manipulate one experimental variable while holding other variables constant. The manipulation of variables results in precise data being obtained.

Educational research adopted the empirical research method along with statistical techniques because the natural sciences enjoyed success while using the normal science paradigm. Associated with the scientific paradigm is a view that it is objective, lawful and value-free. Since the paradigm has these attributes connected with it, data that is obtained from such a method also acquires the same attributes and conclusions that are drawn are seen as certain. Despite the success of the empirical paradigm in the natural sciences many educational researchers began questioning the appropriateness of this style of research in education (Power, 1976; Roberts and Russell, 1975; Lowery, 1980; and Jacknicke and Rowell, 1984).

The predominant criticism is research conducted in the scientific paradigm fails to yield significant results. Typically, the results of these experiments read no significant difference or when a similar study is conducted the results of the experiments are in conflict.

Roberts and Russell's (1975) paper is a description of an alternative approach to research in science education. Their approach involves identifying important issues in science education and through the application of philosophy, develop theoretical perspectives from which phenomena in science education can be studied. The authors identify informal analysis as a powerful philosophical technique that lends itself to the development of theoretical perspectives. Informal analysis is concerned with the actual usage of terms and actual practice of individuals. The next step in their approach is to translate the theoretical perspective to a science education context and develop an analytical scheme by which particular phenomena are studied. Refinement of the analytical scheme occurs through feedback from the analysis of the phenomena.

Roberts and Russell's paper describes several studies that employ the alternative approach and they make a detailed examination of a study performed by Russell. With respect to Russell's study it demonstrates the possibility of examining science education phenomena from an alternative approach. As an overall conclusion to their paper they indicate the approach is a promising alternative to existing research paradigms.

Power's (1976) position paper describes the development of three paradigms in science education: agricultural-scientific, anthropological and philosophical. The agricultural-scientific paradigm is one which is based on the scientific method. There is a dissatisfaction with research based in this paradigm because the results are inconsistent and the research lacks impact. Although there is disenchantment with the empirical method Power states it will remain the dominant force in educational research. In his words, "The politics of research are such that normal science is the norm; the politics of education has not yet created a crisis in educational research and no revolution is in sight, but there are signs of disquiet (p. 581)." Power briefly describes the anthropological and philosophical paradigms noting their strengths and weaknesses. He concludes that despite the scientific paradigm having limitations it should not be totally abandoned in favour of the new approaches. He argues for researchers being fully versed in a particular paradigm but also being aware of the contributions of the other paradigms.

Lowery's (1980) paper deals with the topic of improving research in science by the use of paradigms. He states the failure of the research enterprise to develop into a field of fruitful inquiry is due to the quality of the methodology and the organization of research objectives. He indicates researchers are guilty of poor research design as well as posing inappropriate questions for the research techniques they employ. To Lowery, the difficulty is deeper than just methodology because present research lacks a purpose and a framework. His suggestion is to move from "a fact-gathering stage in which basic elements of problems are discerned and identified to a natural history stage in which the description of elements is emphasized and finally to a theory formulation stage in which inferences are added to facts and organization to obtain concepts and testable hypotheses" (1980, p. 277). In effect, Lowery is arguing for the movement from the scientific paradigm to a situational paradigm.

Jacknicke and Rowell's (1984) paper begins with a discussion of paradigms and how they unconsciously guide people's actions. The authors contend a paradigm provides an orientation for an individual's perspective of the world. To illustrate this concept Habermas's tri-paradigmatic framework is outlined. The consequences of adopting a particular paradigm are given with respect to individuals' conceptions of knowledge. The paper then discusses the interrelationships of world views, school science and science education research in terms of Habermas's paradigms. Although the paper is critical of the empirical-analytical approach, the conclusion reached is science education needs a variety of views because research in the area is best accomplished from a number of approaches. As an overall conclusion Jacknicke and Rowell imply that particular questions in science education research are best studied through particular paradigms and it is short-sighted of researchers to dismiss alternate paradigms.

By the early 1980's qualitative research methods were becoming more common in science education. Roberts (1981), Rist (1982), Smith (1982) and Welch (1983) describe the benefits of employing a situational approach for collecting and interpreting qualitative data. A commonality among the four researchers is the necessity of understanding the situation that is being studied so that the data are representative of the individuals involved. The researchers stressed the importance of observing, discussing matters of concern and becoming involved with the participants in order that the multiple realities of their situation is understood. Qualitative research is not viewed as a method which will supplant the empirical method. All four papers present the idea that different aspects of research questions are best studied by particular approaches and thus it is short sighted for science educators to ignore either qualitative or quantitative approaches. Welch provided descriptions and examples of both research modes and concluded by indicating the strengths and weaknesses of each. Smith alluded to difficulties in naturalistic research methods but she concluded that if naturalistic techniques are properly and conscientiously applied research in science education is more scientific. The availability of a variety of methods allows researchers to investigate questions from different perspectives and as a result obtain a more complete picture. Despite the difficulties associated with situational research, our understanding of educational situations is increased by naturalistic research methods.

Science education and conceptions of science

A frequently cited aim for secondary school science is to provide a background for individuals in society (Aikenhead, 1980, p. 26; Alberta Department of Education, n.d., p. 2; Hurd, 1970, 1975; Mackay, 1971). When research dealing with this aim is examined it is seen that researchers evade the issue of offering reasons for providing such a background. Pella et al. (1966) state science is taught to prepare scholars in science, to provide background for technologists or to provide individuals with a general education for effective citizenship. In his discussion paper Aikenhead (1980, pp. 26-27) offers similar reasons for teaching science and he criticizes science curricula because they are designed for the 5-10% of high school students who enroll in post-secondary science courses. His criticism is important because he has raised a significant problem. The problem is that students are taught content and techniques as if they were continuing in the sciences at a higher level when in fact only a small number of students benefit from such instruction.

Wayne Welch (1979) provides an explanation for the existence of the "teaching for society" position in his summary of the development of science curricula from 1955 to 1975. In the early 1950's scientists and science educators became concerned about the quality of science education in United States high schools. They were concerned because few high school graduates entered university science faculties and many of those who did encountered difficulties. This concern in conjunction with the political climate and the appearance of a book on the supremacy of scientific manpower in the Soviet Union stimulated the United States government to act. The National Science Foundation (NSF) provided approximately $695 million, over a 20-year period, for curriculum development and teacher-training activities. One curricular series that was developed was the Biological Sciences Curriculum Studies (BSCS) materials. The BSCS curricula attempt to place emphasis on the nature, structure and unity of biology as a discipline as opposed to specific information. By stressing the structure of the discipline (Schwab, 1964) BSCS materials are devoted to the education of future scientists and they are not directed to the general education of individuals in society. Macdonald (1975, p. 291) concludes that Schwab's conception of curriculum is an example of a technical orientation. Perhaps the orientation accounts for the fact that the structure of the discipline became equated with content in many NSF curricula.

As present science curricula stress teaching the structure of scientific disciplines, many curricula are unrealistic for the majority of students as they are not furthering their science education. The curricula are unrealistic because of the stress on content and the adoption of a technical-analytical orientation. The researcher contends this orientation is offered almost exclusively in school biology while intuitive elements of artisanship are ignored. It is on this basis that science educators need to be aware of the constitutive elements of biology, what their own conceptions of biology and biological knowledge are, and how students conceive biology and biological knowledge.

The question of conceptions of science has been a concern in science education for some time. Pella et al. (1966) conducted a survey to determine the referents included in the literature pertaining to scientific literacy. The survey examined references from 1946 to 1964. The authors identified scientifically literate individuals as those people who have an understanding of (a) basic science concepts, (b) nature of science, (c) ethics that control the scientist in his work, (d) interrelationships of science and society, (e) interrelationships of science and humanities, and (f) differences between science and technology. Analysis of the literature revealed that the first three characteristics were considered more important than the last three. This decision was based on the frequency with which individual characteristics appeared in the literature.

One of the most commonly stated science objectives is the attainment of an understanding of the nature of science. Prior to Pella _et al_. identifying this objective as a characteristic of scientific literacy researchers investigated the question of whether or not high school students acquired a valid understanding of the nature of science (Mead and Metraux, 1957). The conclusion reached was that students typically had not acquired an understanding that was in agreement with the researchers' conceptions of science. On the basis of their results they hypothesized that the reason students failed to acquire an understanding of the scientific enterprise was that science teachers were not teaching the nature of science. There was a further inference to the effect that the science teachers were inadequately trained. Kimball (1968) studied this phenomenon and he argued that in most of the studies the research designs were faulty because the researchers used nonrepresentative samples of teachers. Kimball's study questioned how well scientists and science teachers display a satisfactory understanding of the nature of science. Kimball concluded that scientists and science teachers did not display a difference in their understanding of the nature of science. As a consequence of this study the argument that high school students are not being taught the nature of science, because science educators are not properly trained, is not valid. A difficulty in assessing Kimball's study in relation to earlier studies is that he seems to operate on the assumption his conception of science reflects the reality of science and thus he is in a position to judge other peoples' conceptions. He did not identify the basis on which he made this assumption, therefore it is difficult to determine if his conclusions are reasonable.

At approximately the time Kimball was conducting his research other researchers were creating a number of objective instruments to determine students' conceptions of the scientific enterprise. In 1973, Aikenhead noted that despite the number of tests available they were used infrequently in research studies. In response to this observation Aikenhead surveyed the available tests and examined only those where 50% or more of the items dealt with knowledge about science and scientists. This criterion excluded instruments that were related to students' attitudes toward or appreciation of science and scientists. As a result of the criterion six tests were reviewed. Of the tests examined five were specifically developed to test a portion of a high school students' knowledge concerning science. One test was validated on college graduates. The review indicated the tests were used to investigate or evaluate courses, supplementary materials, teaching strategies and teacher characteristics. Aikenhead concluded the tests were used infrequently because they were generally unsuccessful in detecting the effects of different teacher characteristics and teaching strategies with respect to students' understanding of science. He hypothesized that the tests yielded no significant differences because they were either inappropriate or the research designs were ill-conceived. As a variety of researchers were involved, this researcher contends that probably not all the studies would be poorly designed. It is probable that there were difficulties within the instruments which led to inconclusive results. One difficulty that may be a factor is that individual tests are constructed from a researcher's framework. The results are students' interpretations of a researcher's conception of science. By studying conceptions of science in this way, a researcher may be introducing variables that influence data. Individual studies would have to be examined to determine if the researcher's orientation was a significant confounding variable.

On the basis of the review Aikenhead concluded that the tests consistently demonstrated the degree to which learning about science and scientists had been stressed in classroom situations but they did not establish students' conceptions of science. In Aikenhead's opinion these types of tests demonstrate a potential for providing qualitative feedback to researchers as the results show what students have learned as well as common conceptions.

A study done by Mackay (1971) raised the issues that prompted Aikenhead to suggest asking qualitative questions about the scientific enterprise. Mackay felt that a considerable amount of time and effort had been spent investigating the development of scientific knowledge but little effort had been expended to determine how students develop an understanding of science. The study used an objective test to measure changes that occur in students' understanding of the nature of science through grades 7 to 10 in selected Australian schools. Mackay found a number of common deficiencies in the students' conceptions of science. The resulting twenty-one areas were categorized into misunderstandings about (1) the scientific enterprise, (2) scientists, and (3) methods and aims of science. The results of the study suggest curriculum materials should be developed so that teachers can systematically develop students' conceptions of the nature of science. Mackay concluded that until this was done the probability of achieving a major science education objective was very remote.

A difficulty associated with Mackay's study is the apparent viewpoint he has adopted in relation to his understanding of science and that of the students. Mackay's choice of an objective test to measure changes in student's understanding demonstrates the idea that knowledge is separate from the knower. Also his choice of the term "common deficiencies" illustrates that he views his conception of science as being correct while students' conceptions are incorrect and in need of being adjusted. It seems Mackay's choice of technical language is inappropriate as it encourages the reader to think of science in a narrow way.

Even though Aikenhead and Mackay suggested alternate lines of research the literature shows researchers are mainly concerned with determining science teachers' understanding of science or developing instruments to measure interpretations of science. Two studies by Billeh and Hasan (1975) and Billeh and Malik (1977) attempted to combine the two purposes. The rationale used in the studies was related to a perceived need to determine the factors that influence science teachers' conceptions of science because this problem is of significance to the design of teacher-training programs. In contrast, Rubba and Anderson (1978) developed an instrument that specifically keyed on a model of the nature of science that had been developed in 1974. The Model of the Nature of Scientific Knowledge originally listed nine factors which Rubba and Anderson condensed to six, owing to overlap within the original factors. The result is the Nature of Scientific Knowledge Scale (NSKS). Perhaps the value of this instrument lies in the fact that it is specifically aimed at measuring students' conceptions of the nature of science. Perceived limitations of the test include the lack of a contemporary philosophy of science within the items. For example, individual questions do not reflect science as being a creative activity in which nonrational elements play a part. Another limitation is that the items predetermine what view of science is to be measured. A test of this nature does not allow for interaction between the researcher and students with respect to clarification, explanation or interpretation of the questions or responses.

Alternative approaches in science education research

Until the mid-1970's typical research in science education was characterized by empirical studies in the "agricultural-scientific" paradigm. Power (1976, p. 584) states that in 1974 at science education research conferences the predominant style of research discussed in the papers was that of the scientific paradigm. He states only three or four papers used a philosophical approach. One of these papers was presented by Roberts and Russell (1975) in which they described an alternative approach to research in science education. Studies referred to in the paper demonstrate that a form of research was being undertaken in which situations were examined from various philosophical positions.

An example of a paper that fits the general description of a study examined from a particular philosophical position is that of Kilbourn (1971). He discussed in detail a method of analyzing the basis on which knowledge claims, presented in science textbooks, are accepted as knowledge. Kilbourn's analytical scheme, or what is termed a clue structure, was based on Scheffler's (1965) work dealing with the truth and certainty of knowledge claims. The significance of Kilbourn's analytical scheme is that it demonstrates an approach for viewing research questions by using points from epistemology.

Another paper by Kilbourn (1980) addresses the issue of how science curricula contribute to students' conceptions of reality. The basis of his argument is an assumption that individuals have a world view. He indicates a world view is a concept which reflects individuals' perceptions of reality and how that reality is known. A mechanistic world view is where the universe is perceived as a machine and causality is interpreted as action by contact. In such a view time and space are absolute, infinite and eternal. Kilbourn concludes world views are projected in textbook statements and for such statements to be intelligible students must assume attributes of particular world views. Kilbourn provides examples in which BSCS materials are examined and he demonstrates that a mechanistic world view is implied in the materials. The application of the analytical scheme to a particular biology textbook demonstrates the capability of the "clue structure" to distinguish world view in teaching materials.

A second paper by Kilbourn (1980-81) expands the concept of world view from individuals to an institutional level. He maintains world views, at the institutional level, are displayed by governments, religious groups, educational systems and so on. Such institutionally held world views influence various aspects of society. He further argues there are six world views and science curricula materials normally reflect four of these views. The four views deal with material that is accepted on the basis of evidential claims. The point Kilbourn makes is that individuals generally develop an eclectic world view because they are not made aware of the abstract assumptions underlying the knowledge they are taught. Kilbourn concludes by arguing for the teaching of the theoretical basis of the world views and the resulting implications of adopting particular views.

Waterman (1982) performed a study that looked at biology education from a philosophical and epistemological point of view. Her question was related to what college biology students thought scientific knowledge was like and where they thought it came from. She was critical of empirical-analytical studies which she termed "standard survey research" and suggested a major limitation of these studies is that students are reacting to researchers' conceptions of science. To overcome this limitation Waterman suggests employing open, nondirective, neutral interviews to determine students' conceptions of science. Her study consisted of developing a twenty-nine item questionnaire which was answered on a five-point Likert scale by 142 students. She used a matrix sampling technique in which thirty students were each asked to interpret a sample of five of the survey questions. Waterman's interviews consisted of questions such as: "What did item 3 mean to you? or Please rephrase this item so that it says the same thing, or has the same meaning for you." A second set of interviews was conducted with eight students and the questions that were asked were along the lines of the following: "How have you or your thinking about science, scientific method and or biology changed since September?" Waterman also states that she asked most of the eight students about their notion of scientific method and how scientific knowledge becomes known. According to Waterman the interview data was analyzed for several purposes. The purposes include establishing face validity and reliability of the survey questions, determining the positions students hold on the issue of nature of knowledge, objectivity and growth of knowledge and finally determining if students perceive their conceptions of biology as changing.

Although Waterman is critical of "standard survey research" she conducted a survey which presented her conception of biology and then had students react to it. She recognizes a limitation to surveys and attempts to overcome the limitation by including interviews. She does not provide an appendix of interview questions and the reader has only a few sample questions to judge the interview section of her study. Based on the sample questions Waterman's study does not reveal students' conceptions of biology; instead it reveals students' reactions to her conception of biology.

Philosophy of Science

The aim of this section of the dissertation is to outline significant shifts in the philosophy of science as viewed from a history of science perspective. The section does not necessarily present the history of science in a chronological fashion. It seeks specific points, times, events or situations that are strategic in terms of shifts in scientific knowledge and the philosophy of science.

The following sections of the dissertation outline significant shifts in scientific knowledge and the philosophy of science. The shifts are discussed because many of the participants' conceptions of biology are rooted in historical and philosophical developments of science.

Conceptions of science are usually not shaped by scientists themselves, rather such notions are shaped by philosophers and historians of science (Wade, 1977; Walker, 1963, p. 21). It is philosophers and historians who describe scientific methods; the process by which old theories give way to new; and differences between theories, laws and hypotheses. The conceptions of science are usually generated by individuals other than scientists. This point raises the possibility of equating "doing science" with "being a scientist." The purpose of the above description is not to equate the two. It is important to recognize that many historians and philosophers of science influenced interpretations of science and these interpretations are in evidence in school biology today.

One of the earliest philosophical traditions in science can be traced to Greek civilization. As the Greek states developed, the geographical position of the country and its economic needs caused the people to come in contact with older cultures. Greek citizens living along the Ionian coast derived material goods as well as knowledge from Babylonians and Egyptian cultures. Crowther (1967) states the Ionians were unable to accept the imported knowledge without critical examination and it is this characteristic that separates Greek culture from earlier and many later civilizations. With the introduction of critical examination of acquired facts the Ionians were the first Europeans to break with the tradition of explaining natural observations by mythological means (Durant, 1933, p. 51; Lanham, 1968, p. 41). The philosophy of the Ionians was based on the assumption that the universe is natural and it is explainable by ordinary knowledge and rational inquiry. With the adoption of this philosophy, supernatural explanation was given a different emphasis and the Ionians introduced the concept of generalized thought to Europe.

When first considered, it seems the rise of generalized thinking is unexplainable. Crowther (1967) argues that it is explainable and offers several factors as part of his explanation. Perhaps the most important factor was the necessity for persuasion among members of the Greek governing class. Greek society was egalitarian in terms of classes and the governing class felt they had the right to reject hypotheses not supported by persuasive proof. The acceptance of statements on authority was contrary to their social habits. Their class of society was structured on the basis of deduction which they used as a method of verbal argument to change the opinion of other free men. Crowther believes generalized thinking was developed to satisfy practical needs of a free group in a particular society. A limitation of Ionian philosophy was it consisted of complicated arguments of logic that were based on few observations. Consequently truth was obscured by the maze of arguments.

With the rise of Athens as the chief city in Greece the limitations of Ionian philosophy became apparent. Social problems existed in Greece at this time and the Ionian philosophy was unable to offer insights into the problems. Athenian philosophers discovered that combining Ionian hypotheses with systematic experimentation did not offer solutions to problems and in terms of science there was a regression to earlier times. Socrates perceived disorder in Greek society and he felt the social problems could not be resolved unless absolute goodness existed. Since he did not derive benefits from Ionian philosophy he attacked it. Consequently naturalistic and experimental science was rejected and Socrates's philosophy of renewing the individual will and establishing absolute goodness prevailed.

Socrates's philosophy was continued in part by Plato. Plato's work combined idealism, scepticism and mysticism into a philosophy where ideas of nature were deduced from human needs and preferences. Plato's views, of what he considered worthy of study, led him to develop the theory of intelligible forms in which the forms or ideas possess the quality of reality that is denied individuals. His theory was applied to the problem of classification. The Greeks viewed groups of things as belonging to classes that were totally separate. They examined the similarities of the individuals composing the classes and ignored relationships between classes.

In an effort to explain observed similarities within a class Plato developed the idea of a primary type to which individuals of a class conform. It was thought that natural objects are constantly in a state of change and it is only the types that are real and unchanging. Consequently, Plato concluded these forms have a real existence and they are the only realities. Plato's philosophy became known as idealism and it had a significant effect on the development of science because objects do not have reality until a person's mind discovers the essence of the class and then the form. The development of experimental science, as we know it, was delayed because Plato felt the forms were the only real and fit subject for analysis. The delay occurred because Plato's forms do not have a concrete existence and experimental science depended on the manipulation of real objects.

An important shift in the philosophy of science occurred when Aristotle broke from Plato's extreme position of idealism. Aristotle recognized the reality of individual objects with the idea of objects being names or mental concepts. This form of philosophy became known as nominalism and was more favourable for the growth of science as we know it (Dampier, 1971, p. 35). Nominalism is conducive to the development of traditional science because it assumes individual objects are real and it is possible to employ objects in investigations.

Aristotle's philosophy indicated "the natural path of investigation" begins with that which is directly knowable and evident to us and moves to what is self-evident and intrinsically intelligible (Frank, 1957). Aristotle's philosophy of science is based on the idea that through direct observable facts general principles are derived that explain what is self-evident and naturally intelligible. Aristotle's scientific procedure of collecting the few available facts and then deducing wide generalizations created a weakness in Aristotelian science that persisted for approximately 1500 years. Dampier (1971, p. 35) identifies the lack of scientific facts and the lack of an adequate scientific background into which the facts are fitted as reasons for the failure of Aristotle's system. In conjunction with his deductive method Aristotle also introduced syllogistic logic to science. With the use of syllogisms premises were used to arrive at a formal proof which was then used as a scientific conclusion. The use of syllogistic logic was inappropriate because science attempts to discover general principles and not generate formal proofs. This criticism of Aristotle's method was not recognized until the middle ages and even then, only by a few scientists. Aristotle's teachings reinforced a form of science that stressed deducing formal proofs from premises that had been arrived at by induction.

Dampier (1971, p.36) states that one of the intellecutal tasks of the early middle ages was the assimilation of Aristotle's works and as a result mediaeval science became a search for absolute certainty along with the premature use of deduction. Aristotelian science led to the assignment of infallibility to fallible authorities and false reasoning in a deceptively logical form.

Beginnings of experimental science

The beginnings of experimental science are found in historical works that discuss the basis on which we accept some principles and not others. Two reasons for accepting a principle were formulated by Thomas Aquinas and described in his unfinished work, Summa Theologica, which was published in 1274. One argument for believing a statement is that results can be derived fron it and thus they can be checked by observation. This form of thought places faith over reason in studying the natural world. The second argument is that a statement is believable when it can be logically derived from intelligible principles. The second argument is a direct application of Aristotelian thought and during the middle ages it was considered to be the higher reason.

The assertion of reason over faith came earlier in the Islamic world than it did in Latin Christendom. In the twelfth century Averroes put forth the Aristotelian idea that reason had primacy over faith. Wallace (1978) states Averroes's justification for believing in the primacy of reason was that he was not a Christian. Averroes was of the Islamic faith and he believed man's passive and active intellect were one and the same thus denying personal immortality. He also believed the universe was not created nor would it cease to exist. These points illustrate that he followed Aristotle's writings.

The commentaries of Averroes were known to thinkers such as William of Auverge and Albert the Great who presented a form of Aristotelianism at the University of Paris in the thirteenth century. The form of Aristotelianism that was taught placed lay learning on an almost equal footing with revealed truth and provided a foundation for the development of mediaeval science.

At approximately the same time that Averroes's interpretation of Aristotelian thought was being taught at Paris, Robert Grosseteste assumed the leadership of Oxford. Grosseteste's interpretation of Aristotle was more in agreement with the teachings of the Catholic faith than that of Averroes. Grossetest's writings on the metaphysics of light suggested an experimental approach (Wallace, 1978, p. 96). Grosseteste's ideas concerning experimentation were taken up by Roger Bacon and when they were combined with knowledge of the Parisian form of Aritstotelianism experimental science became a possibility.

Not all scholars of the middle ages believed in the supremacy of Aquinas's second reason. During this time there was a gradual shift in philosophy that marks the transition from Aristotelian to modern thought. Roger Bacon has been identified as a scientist who recognized the weakness of nominalism. He stressed the importance of deriving results from the statements and then checking the results by experiment (Crowther, 1967, p. 51). Through the combination of scientific criteria and experimental methods it can be said that Roger Bacon's work was an important factor in the early stages of modern science. He was one of the first scientists to appreciate the role of experimentation in establishing what is considered scientific knowledge.

The next important shift in the philosophy of science occurred when Francis Bacon argued that science was not progressive and to become so, a new scientific method was needed. He based his argument on the principle that if new knowledge was desired science needed to abandon scholastic philosophy and the ancient method of deduction. Francis Bacon stressed the need to end haphazard experimentation and develop an organized scientific method. His contribution was the realization that scholastic philosophy did not generate new knowledge nor did the Aristotelian method generate reliable scientific knowledge. He believed by collecting all available facts, making all possible observations, performing all feasible experiments and then collecting and tabulating the results, the connection among phenomena would become apparent and general laws describing the connections would emerge. Francis Bacon advocated a purely inductive method, which was directly opposite that of Aristotle. Feibleman (1972, p. 119) states that of the philosophers of science "Chief among these is Francis Bacon, who believed that deduction plays no role in the scientific method." As described, the pure Baconian method involves a scientist employing insight or intuition to generate, through the process of induction, tentative hypotheses that are in agreement with observed facts; then through a process of deduction the consequences of the hypotheses are determined and then tested by observation or by experiment (Feibleman, 1972, p. 181). If the tests indicate discrepancies, the Baconian method implies returning to the hypothesis stage and working through the method repeatedly until a hypothesis is found that is in agreement with the original observed facts as well as those generated by the experiments. This method is based on the assumption that the method is correct and the facts are wrong.

Despite Bacon having little influence on his contemporaries (Dampier, 1971, p. 126) the method that carries his name has directly influenced science education. Textbooks such as Modern Biology (Otto and Towle, pp. 5-6) clearly outline a slight modification of the Baconian method and state "The steps in this research method are logical and orderly. In fact, they are simply a system of common sense." The researcher contends that such a presentation is an oversimplification and misrepresentation of science.

Many writers imply that experimental science is where a technique of experiemental inquiry is used. The technique consists of developing a possible theory about a phenomenon that is to be investigated, then predictions of the theory are made and controlled experiments are devised to test them. The more rigorous the test, the more acceptable the results. Criteria for the testing procedure is the amount of experimental evidence, rigour of the arguements and precision with which the predictions are formulated.

The requirements for experimental inquiry first appeared in physical science investigation during the 1600's. These investigations led to the formulation of a general experimental theory. The new theory incorporated results of previous experiments, gave insights into present observations and suggested new experiments to test the insights. The experiments reordered the subject giving it direction and coherence. Hence, the development of experimental investigations mark a significant point in the philosophy of science. In biology, experimental techniques did not lead to the development of experimental biology. The new philosophical position led to doubts about biology ever becoming an experimental science (Gasking, 1970, p.5)

William Harvey was one of the first biologists to be influenced by the philosophy of experimental inquiries. He combined dissection and vivisection with simple investigation. The problem Harvey investigated arose directly from making observations during dissections and noting they were in disagreement with Galen's theories. Harvey argued against the Galenic assumption that the movement of the heart and lungs were the same and the vein-like artery could perform the three tasks Galen assigned to it. Harvey also disagreed with the idea that all blood was carried from the right to the left side of the heart through pores in the septum. He disagreed with this idea because his dissections did not reveal evidence of such pores.

Among Harvey's accomplishments was a detailed description of the action of the heart. He also worked on the systemic circulation and calculated the amount of blood entering the aorta per hour. He did this by first counting the number of heart beats per minute and having measured the amount of blood an excised heart could hold he concluded that amount of blood entering the aorta was greater than the amount of blood in the body. On the basis of this conclusion he decided blood leaving the heart through the aorta must be returning via the vena cava.

Harvey's simple experiments demonstrate an experimental technique in that a hypothesis is directly confirmed by showing theoretical deductions are in agreement with direct observations which did not play a part in developing the theory. His work treated the human body as if if were a machine (Lanham, 1968, p. 220). He examined various structures to determine how the whole worked. He was mechanistic in that he compared the heart to a pump and the valves in the heart and veins to mechanical valves.

Mechanistic view of science

Ancient science was based on the assumption that general principles were derivable from intelligible principles. In Greek and early mediaeval science the intelligible principles were based on the belief that everything had a specific nature and acted according to it. This view was termed the organismic view of science because all objects were viewed as if they were organisms. The premise on which the organismic view was based was that the actions of organisms are intelligible. With the introduction of induction and experiment to science there was a corresponding shift in how science was viewed. The organismic view was replaced by a mechanistic view.

The mechanistic view arose because of a combination of factors related to the work of Galileo, Descartes and Isaac Barrow. With the shift in philosophy from scholasticism, where nature is made for man, to that of empiricism, where man is part of nature, Galileo began a search for mathematical relationships in natural phenomena. One area Galileo applied the new philosophy to was terrestrial dynamics. One of the first steps was to delimit the problem of dynamics and in doing so he gave time and distance specific mathematical forms. By defining time and distance exactly, Galileo made it possible to analyze the two concepts quantitatively rather then qualitatively.

Descartes regarded physics as reducible to mathematics which in turn was reducible to mechanism. He even thought of the human body as a machine (Dampier, 1971, p. 135). Descartes was the first person to formally establish a complete dualism where there is a clear distinction between mind and matter, soul and body.

Descartes applied the principles of terrestrial dynamics to phenomena observed in the heavens. His application of dynamics was based on the assumption that the physical world consists of closely packed space filled with matter. In such a world, motion is due to one object coming in contact with another object. The motion occurs in closed circuits because there is no space into which an object can move so that one object can pass another. Instead of space or a vacuum between two objects, Descartes believed there was an invisible primary matter or ether that filled all space. Based on his conception of the world he developed a theory of vortices to explain motion. The theory reduced the universe to a machine which was expressed in mathematical terms (Gasking, 1970, p. 28).

Descartes viewed man as having a rational soul but his body was the equivalent of a machine. His mechanistic position was based on two assumptions: one, there is an analogy between organisms and machines, and two, nature is governed by simple general laws and thus vital functions involve only substances and processes found in inanimate nature. Harvey had successfully used the first assumption in his work on blood circulation but he had reservations about viewing man as a machine. Descartes's mechanistic view influenced the development of biology and almost all biologists accepted his two assumptions for approximately the next 100 years (Gasking, 1970, p. 30). The adoption of Descartes's philosophy by biologists brought them very close to physical scientists and biology became dependent upon physics.

A group of English scientists continued experiments based on Harvey's work and their experiments focused on respiration and the functions of the blood. The experiments were an attempt to apply mechanistic principles. For example, Robert Boyle obtained a new vacuum pump that allowed him to partially evacuate a cylinder and he tested the effect of a lowered air pressure on animals and lighted candles. He finally demonstrated that animals live slightly longer if the air is slightly compressed and he concluded air either absorbs sooty vapours of combustion and respiration or it plays an essential role in combustion and respiration.

Robert Hooke repeated an experiment of Vesalius's. Hooke removed the chest, ribs and diaphragm of a living dog and kept it alive by blowing air into the lungs through the trachea. He also pricked the lungs and kept the animal alive by passing air through the lungs thus demonstrating that the movement of the chest and lungs is only necessary for the exchange of air. This experiment disproved that movement of the lungs accounted for circulation by moving the blood.

Richard Lower also continued with experiments based on Harvey's work. Lower repeated Hooke's experiment but noticed blood entering the lungs was dark red but bright red when leaving, providing air continued to flow through the lungs. If air was withheld the blood remained dark red. He also noticed that if a container of blood was exposed to air the top layer was bright red but immediately below that it was dark red. He further noticed if the bright red layer was skimmed off the dark red layer became bright red upon exposure to air. He concluded the colour change was due to the blood absorbing nitrous particles from the air and then losing them to the body's organs as the blood circulated.

In the mid 1600's mathematical principles were being applied successfully to problems in the physical sciences but they had not yet been applied in biology. Giovanni Borelli did so. He analyzed animal movements mathematically by applying Galileo's analysis of the strength of materials. Borelli accepted the idea that natural processes were the result of motion of small particles. His calculations of the force per unit volume of human jaw muscles led him to feed glass beads and cubes to turkeys. Since the birds' gizzards crushed the glass beads he concluded their stomachs developed more force per unit volume than did a human's jaw. He realized that digestion involved more than pulverization but lacking a chemical theory he was unable to proceed. Experimenters such as Boyle, Hooke and Lower encountered the same difficulty because there was a lack of chemical theory that provided explanations of the components of air (Gasking, 1970, pp. 30-45).

Developments in biology lagged at this time despite the existence of iatrochemists. Iatrochemists were individuals who combined physiology and chemistry. The combination of these two fields should have been productive but since the iatrochemists invoked mysticism into their explanations the majority of scientists dismissed their claims. The first successful attempt to combine physiology and chemistry was made by Francois Dubois. He was not an iatrochemist; instead he viewed organisms as machines that functioned because of chemical changes. He and his students studied the chemistry of digestion but lacking chemical techniques to analyze digestive secretions and food composition they were unable to describe the digestive process.

According to Gasking (1970, p. 48) the failure of physiological experiments to make advances was due to the attempted application of mechanistic principles and this resulted in physiological experiments almost ceasing by the end of the 1600's. The failure of biology demonstrated the need to abandon mechanistic principles but Descartes's mechanical universe persisted because a few simple laws agreed with physical phenomena.

A further complication of the mechanistic view was introduced by Isaac Barrow. He was influenced by Galileo's conception of what was appropriate for scientific study. As previously mentioned, Galileo carefully delimited problems and employed experimental and inductive methods along with mathematical deduction when investigating a problem. If a problem was not amenable to these conditions he did not consider it appropriate for study. Barrow believed the object of science is to study the world that is perceptible to the senses; particularly aspects of the world that demonstrate quantitative changes. To avoid a circular argument when discussing time and motion Barrow stated time and space are absolute, infinite and eternal. Barrow's conception of time and space gave rise to the idea that space extends evenly, without limit and time flows constantly onward without the interpretation of humans. Barrow's statement represents time and space as being independent of human knowledge, perception and interpretation. As such, time and space have an existence of their own (Dampier, 1971, p. 138).

Sir Isaac Newton's development of mechanics was affected by Barrow's conception of absolute time and space. Newton distinguished between relative time and space, as perceived by humans, and absolute time and space that exist in their own right. Along with the development of Newtonian mechanics there was also the development of an observer-observation relationship. The relationship that was held by individuals during and after the development of terrestrial dynamics was one where masses move in absolute time and space and are capable of being held in the mind (Robinson, 1969, p. 16). An observer is one who is in the centre of the universe surrounded by objects that can be perceived by the senses and understood by the mind. By adopting a mechanistic view, all qualities were reduced to mechanical ones and scientists were able to assign numbers to the qualities. The fact that the qualities had a mathematical value made it possible to understand the world.

The failure of biology to become an experimental science, through the application of mechanistic principles, was masked by a change in thought during the later part of the seventeenth century. Geographic discoveries associated with exploration and colonization switched peoples' thoughts from man to the world of nature (Lanham, 1968, p. 93). Explorers were returning to Europe with a huge number of previously unknown plants and animals and classification dominated biology through the eighteenth century. The change in thought coincided with the acceptance of a mechanical universe because theologians believed attributes of God could be understood by studying His works. Living things with their variety and intricacy seemed suitable for studying the attributes of God because the universe was viewed as His creation. Thinkers of this time developed a new philosophy of nature that included relationships of the physical world and the theory of vitalism.

Vitalistic view of biology

A number of variations of vitalism developed over the history of biology but they were all based on a vital force which accounts for the unique characteristics of life. According to Birch and Cobb (1981, p. 77) versions of vitalism were considered as recently as 1950. Hein (1972, pp. 159-161) puts forth a position that vitalism is normally of historical interest in biology and most researchers treat it as a progressive conception of biology that has been shown to be in error and it is no longer an issue. Hein contends that vitalism is a meta-theoretical controversy and it is still evident in modern biology. Observations made by the researcher indicate vitalism is an issue in school biology. This point is considered in Chapter IV.

A vitalistic theory was first introduced by Georg Ernst Stahl in 1708. In his book, Theoria medica vera, he considered the differences between a living organism and a chemical compound. Stahl was impressed by the fact that organisms maintain their identity although they are constantly changing. He considered this ability to resist change as evidence of a vital force (Gasking, 1970, pp. 55-56). Stahl's argument for a vital force was based on the idea that since physico-chemical laws could not explain observations associated with experiments performed on living organisms it was assumed that each organism was controlled by a vital force termed the "ens." He believed organisms were made of the same material as the inanimate world but the ens was necessary to give inanimate materials life. Associated with Stahl's conception of a vital force was the idea of a "superior acting cause." This cause was not dependent upon the inanimate materials of an organism and it did not function as a direct aim for the organism. As such, Stahl's superior acting cause determines the ens which accounts for characteristics we attribute to life.

In the mid 1700's the mechanistic position in biology was in decline and the alternate position of vitalism became popular. The dismantling of English physiological research with its mechanistic explanations was accomplished by John Hunter in the 1770's. He prepared a series of papers in which the techniques and assumptions of a new physiology were outlined (Brown, 1974, p. 181). Hunter's position denied the possibility of mechanistic explanations and focused on the "living body's unique and complicated behaviour." He invoked a vital force to explain observations made while performing experiments on the body temperatures of animals. Hunter destroyed the position of mechanistic physiology in a branch of biology with the combination of his experimental observations and the introduction of a vital force.

Decline of the mechanistic view of science

The mechanistic view began to break down during the last half of the 19th century (Santillana and Zilsel, 1970, p. 89) when Maxwell developed fundamental equations to explain electromagnetic waves. He also obtained the same equations by a complicated mechanical analogy that subsequently generated logical inconsistencies. For his analogy to be functional a propagating medium, ether, was required. The ether had to penetrate everything as well as behave mechanically as a solid body; consequently mechanical models were viewed as being redundant. In the physical sciences, the development of the quantum theory led to the final breakdown of mechanism. Heisenberg's uncertainty principle forced physicists to either give up established laws of nature or alter the mechanistic view of science (Margenau, 1950, p. 42). The establishment of the validity of specific laws of nature caused the mechanistic view of science to be renounced.

In the biological sciences the mechanistic world view that depicts a finite, static universe consisting of hierarchically arranged scientific facts began to break down with Darwin's development of the theory of evolution. The rediscovery of Mendelian genetics gave additional impetus to changing the world view and the development of molecular biology further accentuated the shift. A static view of the world has been replaced with one of an apparently boundless universe that is constantly changing.

Logical positivism

The view of logical positivism evolved out of the Vienna Circle in the 1930's and it had a significant impact on science as it is viewed by scientists and the public (Margenau, 1950, p. 18; Wade, 1977). The philosophers of the Vienna Circle developed a philosophy known as logical positivism which maintained science is a strictly logical process (Joergensen, 1970, p. 4). According to this view, scientists advance a theory on the basis of inductive logic and then test it by empirical means deductively derived from the theory. If the new theory provides better explanations than the old theory, the new theory is adopted. Through the acceptance and rejection of theories science moves inexorably closer to the truth. A prime concern of this group is to concentrate attention on the certainty of the results of science (Neurath, 1971, p. 18). Characteristically the members of the group picture science as a two dimensional structure into which missing pieces must be fitted. In Neurath's words, "The 'mosaicists' are not only inlaying the stones but also changing certain stones for others and varying the whole pattern" (Neurath, 1971, p. 3). Such an analogy leads to misrepresentations of science because a scientist is seen as an individual sorting existing pieces of knowledge until he discovers the proper combination that fits the space in his mosaic. Such a view intimates scientific knowledge will be ultimately complete, just as jig-saw puzzles are ultimately complete. Wade (1977, p. 143) states logical positivism "deliberately ignores the historical context of science as well as the psychological factors which many people would consider important in science, such as intuition, imagination, and receptivity to new ideas."

A contemporary view of science

Since the development of logical positivism a group of contemporary science historians and philosophers have recognized that the scientific enterprise is influenced by a logical structure as well as human factors. The analysis of scientific thought by Feyerabend (1975, 1980), Kuhn (1962), Polanyi (1962) and Medawar (1969) have demonstrated that the scientific enterprise involves nonrational procedures. In his essay, The Unaccountable Element in Science, Polanyi (1962) shows how intuition is important to scientific discovery and the formation of scientific knowledge. Based on the evidence of perception, he argues that scientists pay attention to foreground and background information of a particular situation as well as the total picture. Once these perceptions are acquired the skill of intuition is employed to see the hidden patterns of the problem. To Polanyi a nonrational aspect of science is involved in the recognition of a problem. The nonrational aspect involves an intuitive leap which he terms illumination. According to Polanyi a scientist recognizes a problem when he is aware of a logical gap in his knowledge. The process of illumination occurs when a scientist conceives of the logical gap in a different way and generates distinctive conclusions. The intuitive leaps that scientists make are not necessarily seen as logical. Medawar (1969, p. 55) reinforced the intuitive aspect of science when he stated the major defect of the scientific enterprise, as it is presently conceived, is the lack of attention paid to the "generative act in scientific enquiry." He interpreted the generative act to be intuition.

Thomas Kuhn's (1962) work demonstrates that the scientific enterprise has a logical structure but human factors influence the direction of science. Kuhn clearly demonstrates that the logical positivists' view of science being headed to an ultimate truth is a naive interpretation of the nature of science. Kuhn develops the position that scientific endeavours are heavily influenced by nonrational procedures. These endeavours have new theories associated with them and if a new theory replaces a current theory, science is not necessarily seen as being closer to the truth. The possibility exists that science moves tangentially to the current position. Feyerabend (1975, p. 175) supports the nonrational position of science and his writings suggest a potential reason for the image of science that the public holds. According to Feyerabend critical rationalism arose from the attempt to solve Hume's problem of induction and to understand the Einsteinian revolution. In summary, critical rationalists take a falsificationist position seriously; argue for an increase in scientific content; avoid ad hoc hypotheses and attempt to be honest in all scientific endeavours. The combination of the philosophies of the critical rationalists and logical positivists gives an inaccurate account of science because science is much more chaotic and irrational than their reconstructed methodological image suggests. The researcher maintains that the view of biology that is presently taught in high school biology is a positivistic view which has been directly influenced by the philosophies of the critical rationalists and logical positivists. Biology is presented as being more rational and precise than it is. There is a dogma associated with the reconstructed methodological image that assumes biology automatically obeys, or ought to obey, the laws of logic (Popper, 1972, p. 6). According to Feyerabend (1975, p. 257) this assertion is neither clear nor true. The assertion is not clear because there is not one specific form of logic that reveals the logical structure of various disciplines. He demonstrates that the assertion is false by offering scientific statements that violate simple logical rules. The idea that science can, and does follow a simple set of rules is detrimental to the creative aspect referred to earlier. The idea that science follows a simple set of rules neglects the physical, historical and emotional conditions that generate scientific change and it makes science rigid and dogmatic.

Until the publication of Kuhn's (1962) essay, objectivity and progress in science were interpreted by many individuals in a narrow manner. With his interpretation of science both objectivity and progress are viewed in a new perspective. The concept of objectivity now includes a realization that a scientist observing a phenomenon influences the phenomenon in some way. The scientist is demonstrating a bias merely by choosing to observe one thing and not another. The recognition of influence and bias makes the present interpretation of objectivity opposite to the original view. The concept of scientific progress is no longer interpreted as a series of cumulative exercises that lead closer and closer to the truth. The idea that science is an activity that gets closer to a goal set by nature is one that is strongly held by many individuals. Kuhn suggests this belief may exist because of the way science textbooks distort the history of science. Kuhn rationalizes this belief by indicating that the distortions occur because of pedagogic efficiency. Kuhn argues that textbook authors provide an interpretation of science history that agrees with the current mode of thought so that students are not required to master outmoded ideas. The effect of this manipulation of history is the impression of a linear, step by step accumulation of knowledge that results in students misinterpreting the scientific enterprise. Kuhn defends purposeful distortion of science history when he says "To fulfill their [textbooks'] function they need not provide authentic information about the way in which those bases were first recognized and then braced by the profession. In the case of textbooks, at least, there are even good reasons why, in these matters, they should by systematically misleading" (Kuhn, 1962, p. 137). The good reasons Kuhn refers to, are related to preparing students to operate in the normal paradigm of science. He defends his argument by appealing to the reader's sense of the development of science. His appeal is based on the need for young scientists being trained in the normal paradigm in order that normal science be allowed to proceed.

Sociology of biological knowledge

This section of the dissertation outlines the customary sociological view of science and indicates why scientific knowledge was traditionally excluded from sociological analysis. The traditional correspondence view of knowledge is presented along with implications this view has for an individual's conception of the world. The correspondence view of knowledge is contrasted by a cultural view of knowledge. An argument is made that biological knowledge is culturally based.

A common conception of knowledge is one which represents it as a product of thought. A conception of this nature views knowledge as something achieved by a disinterested individual who perceives an aspect of reality and after contemplating it generates a verbal description which is accepted as knowledge. Such knowledge is considered valid if it shows a correspondence between reality and an individual's perception of reality.

A correspondence view presents knowledge as a product of isolated, disinterested individuals. It assumes individuals do not affect the connection between reality and its representations. An individual's perception of reality is independent of his interests, expectations and experiences. Knowledge is a function of reality itself and individuals generate it through contemplation. Since knowledge is free of man's influences it can be tested by an individual who is capable of comparing it with reality. The comparison can be made because the correspondence with reality is independent of the situation in which it was generated. Barnes (1977, p. 2) indicates the previous points are associated with knowledge because it is usually thought of in terms of a visual metaphor. In his words, "We talk of understanding as 'seeing', or 'seeing clearly'; we are happy to talk of valid descriptions giving a 'true picture'. Similarly we are able to characterize inadequate knowledge as 'coloured', 'distorted', 'blind to relevant facts', and so on."

The correspondence view of knowledge is contrasted by a cultural view of knowledge. Barnes (p. 2) indicates knowledge is increasingly "being treated as essentially social, as part of the culture which is transmitted from generation to generation, and as something which is actively developed and modified in response to practical contingencies." A conception of socially derived knowledge indicates it is not produced by disinterested, passive individuals but by social groups involved in particular activities. Knowledge that results from social groups is not seen as an object that mirrors reality; it is interpreted in relation to reality, the cultural context in which it developed, as well as the objectives and interests of the social group.

As previously mentioned in Chapter II the classical study of the sociology of knowledge, as advanced by Mannheim, Scheler and Durkheim, excluded scientific knowledge. It was excluded because it was viewed as a special form of knowledge that was not influenced by culture. Mannheim's (1936, p. 3) book, Ideology and Utopia, presents the position that knowledge is socially derived. In his words, "the sociology of knowledge seeks to comprehend thought in the concrete setting of an historical-social situation out of which individually differentiated thought only very gradually emerges. Thus, it is not men in general who think, or even isolated individuals who do the thinking, but men in certain groups who have developed a particular style of thought in an endless series of responses to certain typical situations characterizing their common position."

According to Mannheim (pp. 164-166) natural science and mathematics are examples of exact modes of thinking and they do not bear the marks of the context of their production. Natural science and mathematics are not perceived as socially constructed because they are assessed according to their correspondence with reality. Mannheim considered them the preferable form of knowledge because he perceived them as value-free. To Mannheim socially constructed knowledge is context dependent and it is inadequate when compared to formalized knowledge.

Barnes (1972, pp. 3-10) demonstrates that Mannheim's treatment of context-dependent knowledge is inconsistent. Mannheim's treatment is inconsistent because he argues that context-dependent knowledge cannot be assessed in contemplative terms but he develops an argument which implies the opposite. Barnes states some of the inconsistencies arose because Ideology and Utopia was a collection of essays written at different times. Although Mannheim rejected knowledge formation on a correspondence basis his work is largely based on this style of thought.

Many sociologists have felt that a special kind of knowledge exists in the natural sciences and it is intelligible only in contemplative terms. A point often ignored in this conception of scientific knowledge is that knowledge is assessed by technical procedures that are institutionalized or culturally based. The recognition of a cultural basis shifts scientific knowledge from a specialized position and considers it part of knowledge with a social dimension.

In 1945 Robert Merton was one of the first individuals to recognize a social dimension in scientific knowledge and he subjected it to an analysis (Barnes, 1972, p. 9). Merton's analysis was functionally based and subsequent research in this line addressed practical questions of how to maximize productivity of scientists, how to achieve the most effective laboratory organization and how to establish criteria for distributing research funds. The functionalist approach dominated research in the sociology of science for the next fifteen years. In the 1960's a shift is noted in sociology of science articles. For example, Mulkay (1969) argues scientific developments are influenced by cultural factors. He cites the case of Immanuel Velikovsky to illustrate a rigidity in the intellectual commitment of scientists when confronted with threatening innovations. Mulkay bases his analysis on the socialization process that takes place as an individual becomes a research scientist. Mulkay's theoretical position is influenced by Thomas Kuhn's (1962) work, The Structure of Scientific Revolutions. Kuhn maintains that technical paradigms of procedure and interpretation are maintained within branches of science and they provide the basis for practice and evaluation of research. He further argues an open rational mind is not the best instrument for recognizing scientific truths; instead an elaborate conceptual and procedural framework is necessary. The significance of Kuhn's essay to the sociology of science is that it points to social factors in science and suggests the possibility of studying science from a sociological approach.

An outgrowth of the sociological approach was studies that examined cultural factors to determine if they influenced the development of scientific knowledge. Sociologists of science began asking questions such as: what is it that guides the research of a speciality?; what makes science a social phenomenon?; what determines the rate of cultural change in science?, and other related questions (Bodington, 1978).

Interpretation of classroom talk

The section on interpreting classroom talk provides a rationale for examining communications that occur in classrooms. The literature suggests that elements of teaching and learning are reflected in communication between classroom participants. The properties of teaching and learning are socially based and in order to understand them it is necessary to examine the production or talk of the social interactions of teachers and students.

An obvious characteristic of a classroom is the amount of talking that takes place. The majority of teachers' and students' classroom time is spent in verbal communication. Whether the communication is in a large group setting or on an individual basis the predominant talk occurs as a public performance. One assumption that is made about a teacher's public performance is that a lesson usually involves verbal expositions of facts and skills. An image of a manner of teaching is associated with the previous assumption. The image is one of a teacher using communication procedures to obtain information from class members; the teacher then elaborates on pertinent points, summarizes and finally provides a synthesis. The assumption and its associated image demonstrate that distinctive features of commonplace settings are not noticed nor are they questioned.

A form of research called interaction analysis was developed to obtain a better understanding of what teaching is and what occurs in classrooms. Researchers involved in interaction analysis extracted essential qualities from verbal communications and categorized them according to a coding system. The coding systems were developed to make sense of the data and trained observers recorded their judgements about the significance of the observed communication acts. The reliability of such category systems was high but the validity of the data was low (Furlong and Edwards, 1977, pp. 122-123). The difficulty of interaction analysis research was that predetermined categories were imposed upon the observations and the data that were collected. Predetermined categories are grounded in a theoretical position and because researchers rarely state their theoretical position in any detail it is impossible to evaluate the validity of their studies.

Furlong and Edwards (1977) and Heyman (1981) suggest an alternative to interaction analysis research. They suggest a form of ethnographic research involving a sociolinguistic perspective be considered when classroom communication is studied. A sociolinguistic perspective is one in which language is studied to reveal how it is organized and how social relationships are reconstructed linguistically (Furlong and Edwards, 1977, p. 125). A basic premise of a sociolinguistic perspective is that an individual's patterns of choice are revealed by the individual including situational features in their linguistic description. Rules of appropriate usage exist in a society and the rules determine what can be properly said. Speakers are aware of these rules and they use their knowledge to maintain or challenge a definition of a situation. Situations are maintained or challenged through 'marked' or 'unmarked' usage. Furlong and Edwards state 'unmarked' usage of communication is what is normal for a situation, while 'marked' usage breaks the rules in significant ways.

Heyman's (1981, pp. 451, 461) position is the study of any aspect of education must include an examination of participant's talk because the "facts of education are constituted through people's talk." He argues the practice of talk produces a social reality because the properties and use of talk generate social phenomena as well as creating a world in which the existence of social phenomena becomes possible. The meaning of talk is dependent on the context of its use but it also creates the context of its use. The reciprocal nature of talk and its context means people's talk reveals aspects of their objective world as well as meanings of that world.

The sociolinguistic approach is operating on the basis that analysis of communication uncovers social meaning. An individual's knowledge of grammar allows him to establish the grammatical meaning of a statement and correspondingly his knowledge of a 'social grammar' allows him to establish the social meaning of a statement. What a speaker means may depend on who he is, when and where he is speaking and his relationship to the listener. Meaning is determined on at least three levels in any communication. The first level is the dictionary meaning of the words. The second level is the syntax or grammatical arrangement of the words. The third level is the relationship of the speaker and the listener. To uncover the meaning of a situation communication needs to be examined on a variety of levels.

In The Language of Teaching, Edwards and Furlong (1978, p. 11) state verbal communication is the main means of transmitting knowledge in classrooms and the verbal encounters that occur are of a distinctive kind. They maintain it is impossible to separate the organization of classroom communication from the management of classroom meanings. Their argument is based on the observation that a central communication system is in evidence in classrooms and it is structured so a single speaker addresses a large group the majority of the time. Generally, private communications are of a short duration and typically within small groups.

Kliebard (1966) analyzed classroom communication on the basis of a game in which basic moves are available to the players. Edwards and Furlong continued with Kliebard's analogy but eventually the analogy breaks down. The breakdown creates difficult questions about what verbal statements are considered significant and why they are considered so. Despite this limitation categories of communication metastatements were identified. A communication metastatement is a statement about talk. For example, when a teacher poses the question, 'Are you getting the message?' it is a statement about a communication that previously occurred (Stubbs, 1976, p.83). Categories of metastatements include attracting attention, controlling the amount and distribution of talk, defining, specifying a topic, checking or confirming understanding, editing or correcting what is said, and summarizing (Stubbs and Delamont, 1976, pp. 159-164). Edwards and Furlong (pp. 24-38, 103-121) indicate that meanings associated with classroom interactions are uncovered when questions about the social structure are examined in terms of communication metastatements. They suggest questions concerning formality and social distance, manner of teaching and the management of classroom questions and answers reveal information concerning the transmission of knowledge.

CHAPTER IV

PARTICIPANTS' CONCEPTIONS OF BIOLOGY AND BIOLOGICAL KNOWLEDGE

Introduction

Chapter IV of the dissertation deals with the analysis of the participants' conceptions of biology and biological knowledge. The first section of the chapter outlines four premises on which the analytical scheme is based. The second section presents the analytical scheme in conjunction with the two papers and the three assumptions which provide a foundation for it. The third section is an analysis of the three teachers' conceptions of biology as a discipline and biological knowledge. An effort is made to relate the teachers' conceptions to possible implications such conceptions have for the way students view biology and biological knowledge. Finally, the fourth section deals with conceptions of biology and biological knowledge as held by thirteen students. The analyses are done on the basis of groups of students. The students are grouped according to the philosophy of biology that they most frequently exhibited during the informal discussions.

Premises of the analytical scheme

The analytical scheme that is employed in the analysis of the participants' conceptions is founded on the principles of the sociology of knowledge, hermeneutics, sociology of science and sociolinguistics. The first premise of the analytical scheme is that knowledge and social structure are related in such a way that they influence each other. The term social structure reflects Schutz's conception of the common sense world in which individuals establish meaning by interpreting experiences. Experiences are interpreted in the Schutzian sense as that which forms the world's history, personal experiences of that world, and interpretations of the world passed to us by other individuals. Teachers and students establish meanings for a selected area of their common sense world because they are involved in the social structure of their world. The participants establish meanings by creating classes with common characteristics. They typify and interpret actions of each other through communication. The participants are members of an in-group; therefore, a system of knowledge is common and meanings that are being developed are taken-for-granted. The meanings contribute to an individual's stock of knowledge which later provides the means for interpreting future experiences.

The second premise associated with the analytical scheme is included in the concept of hermeneutics. An interpretation of the participants' talk becomes possible because Gadamer's hermeneutical theory offers a clarification of the understanding of a text. The process of interpretation involves the analysis of meaning shared through communication. The analysis scheme does not attempt to reconstruct the authors' meanings and then interpret or explain them. The analysis scheme examines the meaning the text has for the researcher and it discloses the text's inherent meaning.

The third premise of the analytical scheme is that biological knowledge is socially constructed; therefore, it is subject to analysis by the sociology of knowledge. This point is raised because the traditional view of sociology of knowledge excludes scientific knowledge from analysis. Recent studies demonstrate that biological knowledge is influenced by cultural factors and this form of scientific knowledge is subject to sociological analysis. This means the points raised in the first premise of this section apply to biological knowledge and an analysis of the participants' conceptions of biology and biological knowledge is possible.

The fourth premise associated with the analytical scheme is included in the concept of sociolinguistics. The notion is that individuals' meanings of the common sense world are reconstructed linguistically and they are revealed in linguistic description. An inference that is made on the basis of this premise is that an individual's knowledge of a social grammar allows him to establish the meaning of a statement in a social context. Hence, a study of a variety of the participants' talk reveals their conceptions of biology as a discipline and biological knowledge. It is the researcher's knowledge of a social grammar in biology classrooms that permits him to establish the participants' intended meanings. A connection exists between the second premise and the fourth premise, the concept of sociolinguistics. The connection is the intended meanings that are revealed through sociolinguistics are interpreted in terms of the participants' conceptions of biology and biological knowledge.

Analytical scheme

The analytical scheme that is used to examine the constitutive elements of the participants' conceptions is based on papers by Esland (1971) and Werner (1978). Esland's paper addresses the issue of explaining classroom interactions and examining the selection as well as the transmission of knowledge in light of alternative sociological theories. Esland makes the point, that at the time of his writing, the perspective of researchers in the sociology of education was primarily neo-positivistic. The term neo-positivism is defined as a view of man in which man is considered a dehumanized, passive object. Sociologists tended to view man in terms of roles in organizational structures. Esland (p. 71) states the neo-positivistic view has its origins in the works of Francis Bacon, Locke and Kant in which man was viewed as a completely rational, knowing subject separated from his social context. Associated with the separation of man's conception of the world and his social context was the idea that theoretical concerns were uninfluenced by situations which gave rise to the theories. The neo-positivistic view is directly associated with the correspondence theory of knowledge that was discussed in Chapter III. According to the neo-positivisitic view a detached individual perceives reality and because of his rationality his description of the natural world is considered knowledge. There is a direct correspondence between the individual's description of the natural world and reality itself. According to Esland the theory of knowledge that is associated with the neo-positivistic view has become the scientific epistemology.

In contrast to the neo-positivistic view of the world and its associated epistemology, Esland places his study and the research it suggests within a dialectic epistemology. According to Esland (p. 71) a dialectic epistemology is based on a view of knowledge which is socially constructed. Esland contends previous research accepted teaching and learning in terms of roles. The intentions, ways of knowing, and knowledge associated with these roles were either ignored or classified under beliefs or values where they were accepted without question. His point is that intentions, ways of knowing, and knowledge are common everyday concerns of teaching and learning. He maintains such points should be questioned and examined. In order to question these normally unquestioned aspects of teaching and learning, Esland assumes all teachers have a subject and a pedagogic perspective that are exhibited in their vocabularies, rationales and theories of knowledge which support their control of students, view of knowledge and preference system for evaluating learning. The observable attribute that reflects a teacher's subject and pedagogic perspectives is the manner of teaching. According to Esland, examining a teacher's teaching style will reveal his pedagogic, subject and career perspectives. In terms of this study these three perspectives represent the teacher's categories of thought through which he makes sense of the teaching and learning process. Esland maintains that asking questions about the pedagogic, subject and career perspectives reveals implicit theories of knowledge, why certain knowledge is taught and professional constraints on the teacher's understanding of his work.

The second paper that influenced the analytical scheme was that of Werner (1978). Although he was concerned with evaluation of educational programs, suggestions he made are applicable to the present study. He examined the evaluation of school programs from the three perspectives of ends-means, situational and critical sense-making. The perspectives reflect the Habermasian orientations referred to in Chapter III.

Within each perspective Werner suggested a series of questions that could be asked concerning the implied view of programs, worth of programs and social relations of individuals involved in the programs. The questions contained within the critical sense-making perspective attempted to disclose perspectives underlying programs, social relations maintained and legitimized through perspectives, sources of the perspectives, the control function of the perspectives, and arguments/criteria/standards for changing these perspectives.

The analytical scheme is based on three assumptions. The first assumption is that a teacher develops an epistemological position which is interpreted by the researcher to be a system of conceptual relations concerning knowledge. The second assumption is that a teacher's interpretation of a discipline is related to his epistemological position. The third assumption is that a teacher does not present the material of a subject unaltered; his interpretations of knowledge are reflected in lesson presentations. Consequently, when students are taught a subject they receive a particular viewpoint of knowledge and of a discipline.

Prior to consulting either paper by Esland or Werner the researcher transcribed the lessons of teacher "A", the informal discussions of teachers "A", "C", and "D", plus the informal discussions of the eighteen student volunteers. The transcriptions of teacher "A"'s lessons and informal discussion were examined for prominent themes. On the basis of the transcription plus classroom observations, the researcher noticed comments which referred to a central lesson theme, the manner in which the teacher controlled classroom communication, a view of biology as a subject, and reasons for the knowledge that was presented. It was noted that very few student-initiated questions were asked. After the themes were noticed Esland's paper was consulted and a theoretical basis for an analytical scheme was developed.

According to Esland (1971, pp. 83-104) a method of examining the teacher's epistemological position is to study the teacher's perspectives. Esland states the perspectives contain inferential structures of public knowledge and as a result an analysis can be made of a teacher's epistemological position. In terms of the present study questions were asked of the pedagogical and subject perspectives because they are directly related to conceptions of biology as a discipline and biological knowledge. Questions concerning the career perspective were not asked as the dissertation is not directly concerned with professional constraints on the teacher's understanding of his work.

Esland's model was modified as some of the questions dealt with issues of the distribution of 'good' and 'bad' students, assumptions about social class and its relation to learning, as well as the influence of chronological age on learning. Questions such as the previous examples are not seen as directly contributing to the teachers' nor the students' conceptions as studied in this dissertation. Consequently, they are not included in the analytical scheme.

The scheme consists of a series of guiding questions that are asked of the pedagogic and subject perspectives. In terms of this study the term "guiding question" refers to a focus which permits the researcher to examine the two perspectives. The guiding questions are:

1. Pedagogic perspective
    (a) What is the theme around which the teaching takes place?
    (b) What is the prevalent mode of teaching that occurs in the classroom?
    (c) What is the interest in the communication process?

2. Subject perspective
    (a) What, according to the teacher's definition, constitutes biology as an area of study?
    (b) What is the rationale for the teacher's knowledge?
    (c) How is the teacher's view of high school biology reflected in the lesson material?

The guiding questions provide a focus by which the lesson presentations, informal teacher discussions, and classroom observations were examined and then interpreted. An interpretation is made by considering the questions Werner (1978, p. 19) raised in his examination of critical interpretation. Specifically, the questions considered are:

1. Perspectives
    (a) What are the underlying intents?
    (b) What are the underlying assumptions?
    (c) What are the underlying approaches?

2. Social relations within perspectives
    (a) What teaching relations are implied?
    (b) What views of students are implied?

3. Control function of perspectives
    (a) What knowledge is selected and neglected?
    (b) Who has the power to control?

Analysis and interpretation

The following analysis and interpretation takes place in two sections. The first section deals with the transcriptions of the teachers' lessons and informal discussions as well as observations made during the study. The presentation of material follows the order of the guiding questions in the analytical scheme. An individual analysis and interpretation is made for each teacher and then a synthesis of the major points of each section of the analytical scheme is offered. The second section deals with the transcriptions of the students' informal discussions. The students' analyses and interpretations are broadly grouped according to the dominant philosophical position of biology that is reflected in the discussions. The interpretations of the students' conceptions of biological knowledge and biology are found in Appendix G. The students' conceptions are discussed according to the philosophical groupings.

Each of the teachers' analyses and interpretations is based on a transcript of classroom lessons, an informal discussion as well as observations made during the presentation of lessons. Owing to the massive amount of material transcribed, a complete transcription is not included in the appendices. A complete lesson transcript for one class of each teacher is found in Appendix D and a complete transcript for the informal discussion for teacher "A" is found in Appendix E. A complete transcription for the informal discussion for one student is found in Appendix F. The following symbols are included in the analyses and interpretations as well as the three appendices:

--- indecipherable statement
... conversation fades to a stop
[] overlap of speakers
A: teacher "A"
B: researcher
C: teacher "C"
D: teacher "D"
Student(s) unidentified student(s)

Jim: identified student

A. Analyses of teacher interpretations

TEACHER "A"

1. Pedagogic perspective

(a) What is the theme around which the teaching takes place?

By focusing on the first guiding question, the transcript of teacher "A"'s lessons and informal discussion was examined for the theme. According to the teacher's introductory statements, the theme was to be "autotrophic nutrition." In examining the transcript the topic of photosynthesis became the surface theme and the importance of autotrophic nutrition was reduced. Within the theme of photosynthesis an underlying theme was observed. The lessons stressed the idea that photosynthesis is the basic process of biology and it is the source of energy for all living organisms. The teacher stated that without photosynthetic organisms, life would not be possible. The general pattern of talk that reinforces this underlying theme is illustrated as follows:

A: ... And so we say the green plant is the bridge for us between sunlight and our own energy needs. You want to look at the green plant then, you can simply say that its role, one of its roles, is to convert one energy form into another. That's pretty well what we mean by sort of packaging food. It doesn't create energy, it simply converts it. It's an energy conversion organism. And the amazing thing is that as far as the ecosystem is concerned the green plant is the only organism that has the enzyme equipment or the pigment machinery to make this conversion from light to chemical energy. And that's what we'd like to stress. That's a very unique or special ability. ...

> ... What I'm saying, we as urbanites really don't come to grips with the significance of the green plants. We think we go to Safeways or Woodwards for our food. We're really going to the garden, to the field, to where the green plants are. We are relying on them very much to do this for us. ...
>
> ... What we're trying to say is the whole life system on earth depends on this ability of plants to make chemical energy packages from light. ...

The preceding three excerpts are contained in a monologue that arose from teacher "A" declaring that a generalization about "autotrophs, or green plants" would be made. The material leading to this generalization was presented to establish elementary biochemical differences between autotrophic and heterotrophic organisms. This was accomplished by the teacher introducing the material to be discussed which was then developed through a series of leading questions. Students' answers were assessed, clarified and elaborated so that the lesson had a direction considered appropriate by the teacher. On the basis of the teacher's material an appropriate generalization would be a summary statement concerning the characteristics of autotrophic organisms. What was offered by teacher "A" was a statement which reformed and refined the presentation for the students rather than summarizing the essential differences between the two types of organisms. Within the teacher's comments were references to the surface theme which was referred to earlier.

The teacher's introductory remarks include the idea that general concepts of autotrophic nutrition are important because they provide a connection between present and past knowledge. Statements of this nature are interpreted to mean that the the teacher is attempting to provide a generalized view of major biological concepts so that students perceive a comprehensive picture of the subject. Although general concepts were stressed, it becomes evident that specific information is what was presented to students. The statement, "We've done the, sorta the, introduction, like laying the ground work. And now we're goin' to focus on procurement, that's really what we're after as students", demonstrates that despite previous recognition of the importance of generalized concepts the significant material consists of precise information. In this instance the precise information consisted of telling students that carbon dioxide and water are the raw materials for photosynthesis and that specific structures within the plant are responsible for obtaining these materials from the environment. Further evidence of the stress that is placed on precise information is found where teacher "A" told students that particular points should be included in their notes. For example, "So put in your notes this way then. A low carbon dioxide opens the stoma. We already said that. And the pH would be, what? Going up or down? If the carbon dioxide is declining are you getting more or less acid? Norm?"

At this point it may be concluded that the importance of the stated theme is reduced and a surface theme becomes stressed. A secondary point is related to this conclusion. The teacher's statements indicate that the stated theme and its related concepts are of major importance but observations show specific information is stressed in classroom presentations.

(b) What is the prevalent mode of teaching that occurs in the classroom?

With respect to the second guiding question it was observed that the predominant teaching strategy was that of recitation. This term refers to the presentation of material by exposition interrupted by questions (Edwards and Furlong, 1978, p. 27). Patterns emerge when sections of the transcript are analyzed for recitation. The following exchange, beginning with a student's response to the question of what molecule other than protein is not produced by Calvin's C^{14} flow chart, demonstrates a questioning pattern that is consistent with transcripts of previous and future lessons.

Student: Lipids.

A: Lipids. The cuticle. We're not goin' to study how the plant makes its lipids. That would be another topic. All we're doing here is suggesting how a plant makes what category of foods? Carbohydrates. We'll ignore how it makes its vitamins, how it makes its proteins, how it makes its lipids. Can a plant make all these things if it's an autotroph? [2 s p] Ya, it doesn't have ---, it makes them all. We'd like you to say this, we can say this is sort of the foundation. Once it has its organic carbon and once it has its carbohydrate then it isn't quite so hard to package the other things. Because the main thing that's in this carbohydrate package that's really hard to capture is what? [3 s p] If you can answer that question you can sort of see the significance of the process. I'll repeat the question. The main things, I'm not sure if that's the right word, the main item that's in these carbohydrate packages that is hardest to acquire from the environment, is what? [5 s p] What's been packaged here? [3 s p] Anybody tell me? [2 s p] Well, I'll give you a clue. It's carried in, in that form. What's been packaged? [4 s p] Oh, I'm discouraged. You lost the main point in the details. Remember that old cliche, you can't see the forest for the trees. Well that's what's happened here. What is it Laurel? [1 s p] What's been packaged that's very hard to package? [1 s p]

Laurel: Energy.

A: Energy. That's what it's all about. And once the energy is packaged then the rest of it is sort of easy. So we've called these green plants what kind of packagers? [2 s p]

Linda?

Linda: I don't know.

A: They're not ordinary autotrophs. They're using what to package, in making their food? [1 s p]

Linda: ——.

A: The question isn't clear. Green plants are autotrophs, true enough. But what kind? [2 s p] Preface that with another word. We said they are what? [2 s p] They are photo- [3 s p] synthetic autotrophs. They are packaging light energy. That's the thing we mustn't lose sight of. ...

In the previous exchange the pattern begins with a student's response of "lipids" which the teacher repeats. The answer is then elaborated and modified so that the next question arises from the student's response. The pattern takes the form of a teacher introducing the topic and developing a series of directed questions. Through the use of directed questions the teacher controls the direction and content of the exchanges as well as students' responses. A convergent questioning style is being used in which a particular issue is focused upon. Because the focus is a specific phrase or word that describes an aspect of nature, each subsequent question becomes more exact. One outcome of this style of questioning is short, specific answers. On the basis of these observations a relationship between recitation and specific information is seen. The perceived relationship is that convergent questions encourage exact answers which students view as knowledge.

Examination of the teacher's questions and the students' replies suggests that recitation coupled with convergent questioning leads to specific information being stressed at the expense of concepts. For example, when the teacher indicated that he was discouraged because the students had forgotten the concept of "energy transfer" in autotrophic organisms, he attributed the students' lack of memory to paying too much attention to the biochemical details of carbohydrate production. The researcher contends this is not the case. Students have not forgotten the concept of energy transfer, they have placed it in a position of secondary importance in what they view as biological knowledge. The reason it is considered of less importance is that information is stressed in both the presentation of material and questioning sequences. The structure of the questions and responses of teacher "A" show that he knew the answer and was seeking a student's response that suited a particular direction. For example, when he asked the question, "Because the main thing that's in this carbohydrate package that's really hard to capture is what?", the answer was obvious, based on the context of the lesson. When this question did not elicit the desired answer of "energy", clues were provided which limited potential answers. In this example the phrases "hardest to acquire from the environment" and "in that form" refer to earlier instructional sequences where a direct link was made between visible light being an energy form that is found in the environment and the observation that green plants package energy in the form of carbohydrates. The responses of teacher "A" also show that he pre-established the answers and was seeking a particular response. In the case of Linda replying "I don't know" to the question, "So we've called these green plants what kind of packagers?", it is obvious that he wanted to hear "photosynthetic autotrophs" as the reply. When this reply was not heard he gave clues and finally treated the question as rhetorical in order to continue.

Another factor that leads to specific answers is the closed nature of the teacher's responses. As a consequence of the teacher predetermining acceptable answers, it is expected students will give short answers that match the teacher's framework. Answers of this type are also encouraged by the teacher elaborating specific points and directing the material to the next question. Each answer is normally followed by a comment, not necessarily on its correctness, but on its relevance to the issue at hand. The following excerpt shows how students' responses of "sunlight" and "food" support the lesson.

A: ... The chemical carrier for the energy that the plant captures has a three letter abbreviation. What would it be? [2 s p] Laurel?

Laurel: ——.

A: Its initials are [ATP. Ya.

Laurel: [——.

A: Not E.T. but ATP. We should have a bumper sticker. If E.T. warrants a bumper sticker, certainly this does. It is the energy chemical of life on earth. I'd like you to, or make notes, this is common to all living forms. Not just in plants. The unique thing in plants, however is they, the green plant, can make this chemical. Not by taking energy from food but by taking energy from what source? Ted?

Ted: Sunlight.

A: From light. And that's the unique part of it. You and I may make ATP also. We use it to run our muscles, to do all kinds of work in our bodies. But we have to make it from the energy that's already in chemical form. And the package of that energy we call? Bonnie?

Bonnie: ——.

A: What do you call packages of energy you buy in Safeway and Woodwards?

Bonnie: Food.

A: Food, ya. We make our ATP from food. The plant makes its ATP from, initially at least, sunlight. And that's the difference in being an auto and hetero. O.K., well that's a very unique ability. For this, we said, not only does the plant need light but it needs something to carry or handle that light. And that light is first packaged or captured, I should say, by that very special molecule we call chlorophyll. And not just any chlorophyll, but what kind of chlorophyll? Bev? [7 s p] We can distinguish one chlorophyll form another with symbols of the alphabet. Do you know your a, b, c's?

Bev: It's chlorophyll a.

It may be concluded that the prevalent teaching mode of teacher "A" is recitation. This manner of teaching encourages a convergent questioning style which results in students giving short, specific answers.

(c) What is the interest in the communication process?

The third guiding question raises the issue of how the teaching mode controls the communication process. The transcript reflects a teacher who controls lessons by directing questions and answers, and who had a specific set of short and long-term objectives in mind when a question was posed. A set of questions converged on a particular point and each subsequent answer became more specific until the objective was achieved. For example, each subtopic was introduced by the teacher who then developed particular points through leading questions. Once a particular answer or objective had been reached, the issues were elaborated and summarized so that continuity existed for the lessons as a whole. As an example of the control the teacher had over the direction of a lesson, the following exchange is offered:

A: ... O.K., let's wind up this little demonstration. Ah, you have already in your notes a conclusion. I'd like you to write it down, based on our data ah, we've collected about geranium leaves and Coleus leaves ah, at least. What could you say, Juanita? [2 s p] There's the problem, what would you say in response to that problem based on the data?

Juanita: Yes.

A: Yes. I would not ah, be quite happy with that. You'd say the question is ... Is chlorophyll necessary for the production of starch in geranium leaves and you'd say yes. In Coleus leaves, yes. Now that is quite correct, but could you give me a sentence answer? Keep it positive now. [2 s p] Yes, chlorophyll is - , or you could just say chlorophyll is ...

Juanita: Chlorophyll is necessary for the production of starch in geranium and Coleus leaves.

A: O.K. I'd be a little more happy with that. Well, we're going to leave that then, significance of chlorophyll, ah for the moment and go to where is it kept? What part of the leaf holds the chlorophyll? Let's take a look at our equation, ah, once more for photosynthesis. What are the two raw materials the environment has to provide to make sugar or starch in the plant? Jean? [2 s p] Is that your name?

Jean: Ya.

A: What are the two raw materials for making sugar or starch? What a plant needs. I have one on the board. What's another one?

Jean: H_2O.

A: H_2O. A plant has to obtain carbon dioxide from the air, water from the soil we said. And in the presence of light we said, or in the presence of energy and put together as starch. But we haven't just demonstrated only if the plant has what inside it? [2 s p] Norm? [3 s p] What traps light?

Norm: Chlorophyll.

A: Chlorophyll. So I'll add chlorophyll to my little summary and then I get starch and sugar or what we call carbohydrates, ah plus something we haven't really been focusing on very much, oxygen and we'll have some water. ...

For example, the teacher structured the questions so that students provide one-word answers. This is illustrated by the question "What are the two raw materials for making sugar? What a plant needs. I have one on the board. What's another one?" For Jean to provide the answer of H_2O, extended thought was unnecessary. She memorized two pieces of information from an earlier lesson and then repeated the name of the compound not provided by the teacher. The answer is then used by the teacher to achieve his next short-term objective.

The previous exchange shows how the manner of teaching controls communication between a teacher and students. When questions and answers are examined, it is seen that the teacher accomplished at least two unstated goals. The first one is that of providing students with additional information, while the second is to check students' memories for particular information. As a result of the manner of teaching and its control over the communication process, the teacher's presentation of biology is perceived in a particular way. Typically, the teacher is seen as an expert who has command of a body of knowledge which is transmitted to those who do not know. The expert image is further enhanced by the practice of asking questions in such a way that it is obvious to students that the teacher has answers which he considers acceptable. By adopting an expert position the teacher places students in the position of being novices and as a result there is a distinct boundary between knowledge and ignorance. In this instance the expert is seen to possess knowledge in the form of specific information which is transmitted to students who are ignorant of biological information, processes and concepts (Stubbs, 1976, p. 100). An implication of an expert image is that students may interpret knowledge to be discrete pieces of information which are passed from one expert to another and finally they are taught in biology classes. The following excerpt from an discussion with a student from teacher "C"'s class illustrates this point:

B: Now you've used the word "knowledge." What does the word "knowledge" mean to you?

Susan: Um, I guess it's just extra information that I know, that I can use.

B: Can you give me an example of a piece of knowledge?

Susan: A piece of knowledge is um, knowing the different blood types is knowledge.

B: So if I was to say I was type O, for example, that would count as a piece of knowledge? Where has that knowledge come from?

Susan: For me it came from Biology 20.

B: It came from Biology 20. And what about the person who originally came across that piece of knowledge?

Susan: They probably did it through experiments, discoveries.

In this instance Susan equated knowledge with specific information that she termed fact. Upon further questioning it became clear that such facts, in her view, exist in reality in the same way physical objects exist and these facts are discovered by biologists just as a previously unknown island is discovered by an explorer. To her, scientific experiments uncover facts and when a sufficient number of experiments are performed the facts are proven and incorporated into courses as biological knowledge. A second implication of the expert image is that students receive the impression that facts are discovered and proven by empiricism. This point is shown by comments such as these:

A: Little chloroplasts. What if I tore a leaf apart and spilled out those little chloroplasts, would one chloroplast make starch? [2 s p] What do you think Juanita?

Juanita: ---.

A: Sure. You'd say sure. Well how would I prove it? And scientists have. They've ground up leaves, they've isolated chloroplasts they've bubbled carbon dioxide through with water and doubled the light and sure enough out comes sugar.

The declarative phrase "And scientists have", carries the message that empirical experiments are a source of absolute proof for observations and, thus, if something is known with certainty, it is transmitted as knowledge from one expert to another. Also within this excerpt is a message that knowledge can be proven and it consists of pieces of information that exist outside individuals. In other words, knowledge is not a creation of people, it exists in reality.

The observed teaching mode and its element of communication control result in biological knowledge being presented in a particular fashion. The manner of teaching lead the researcher to perceive biological knowledge presented as an item that exists in reality. In discussing this perception with teacher "A" he indicated that it is opposite to his personal belief. According to his view there is a "reality of nature and the scientific process provides one way of understanding this reality." The teacher expanded his view when he was asked if he taught the nature of science to biology classes.

A: I do, [make a specific point of dealing with the nature of science in biology classes] ah, for about two periods, one and a half to two periods at the beginning of the course and my thrust at that point is simply to say we are limited in

B: Um, huh.

A: what we can study in this course. Science is a limited way of knowing and secondly it does not produce truth. And those are sort of my two thrusts. Um, so if we run into ideas in this course that seem to be in conflict with some other ideas we have, the student has picked up along the way from a different way of knowing, it does not necessarily mean to say that what we're learning here is sort of ah, more or less true than what you've learned in some other area. In a sense you can look at the world from different angles and see it from different perspectives and both are legitimate.

B: Um, huh.

A: And I'm trying to reduce the level of threat particularly keeping in mind those students in the class who come from, from ah, a world view greatly influenced by fundamentalist Christianity.

Comments such as "you can look at the world from different angles and see it from different perspectives" shows that the teacher believes knowledge results from a variety of systems. To him, biology is only one way of obtaining knowledge. In the following excerpt he indicates that theology is also a source of knowledge.

A: ... Some of these people [early biologists] were members of the cloth. I should say they were clergy. They were not scientists in the sense of totally employed, getting research grants from the government of their country, they weren't being sponsored, shall we say, by some big company to do research. They were not staff at universities in the faculties of science, they were doing science as a hobby. Why the clergy? Why did people in the church, as ministers, go tampering around with some of these questions? Anybody give me an idea on that? [3 s p]

I find that kind of intriguing because today some of us have the misconceived notion that religion and science are antagonistic. That is they don't get together very much. And we even see this in the form of debates. And we even see this happening at our [own] auditorium, and it will draw a

> large crowd. I didn't see the record in the paper of last Thursday's meeting. Does anybody know? [2 s p] Anybody there? Nobody went to hear a lecture on the Grand Canyon? Well, what we're saying is it used to, maybe it's not that anymore. I went to one and the auditorium was full. They bused people in from outside [the city] all around to hear this guy talk about issues of religion as he saw it. And here we find people in the church were doing what we would call, today, science. Can you give me an explanation why the two were quite comfortable. Yet doing this kind of questioning about nature along with your interests in theology. ... Well, on summarizing my --- suggesting that people in, dealing with theological issues find nature an area of support. They could go to nature and say isn't nature wonderful, isn't nature beautiful, doesn't it show tremendous design? And they would say that is certainly quite strong evidence for the existence of the subject of my other interest, God. And so to research nature, or to look into nature was supportive in those days of their belief or their faith system. ...

. In summary, the teacher's comments show that both biology and theology are presented as ways of knowing. His view presents biology as one way of gaining knowledge. To him, the scientific process establishes a link between the reality of nature and the creation of knowledge by man.

The third guiding question also examines the manner in which student-initiated queries are handled and the degree to which they are accepted as being logically admissible, or appropriate, to the present discussion. Upon studying the transcript it is seen that student-initiated questions are related to both communication control and the expert image. In the complete transcript the lack of student-initiated questions is notable. Five instances were found in which students posed questions to establish or clarify their understanding of a particular point. In two of these instances the queries dealt with examination questions that had been recently graded or were upcoming. Of the remaining three, two were stimulated by the teacher-directed discussion and the third instance was student-initiated. The first two instances are illustrated by this excerpt:

A: ... And by the way, from your test I got the impression you don't understand the word pigment. You tended to confuse it with a plastid. You thought pigments and plastids were the same things.

Student: Isn't a leucoplast a pigment or something like that?

A: You've illustrated my point very well. What is the meaning of the word pigment? Is it an animal? Or is it an organism? Is it part of a cell, like an organelle? ...

The student's question was stimulated by the teacher-directed discussion and it was answered by referring to a dictionary definition which the teacher read to the class. Once again the teacher is seen as an expert providing information. What is lacking is evidence that the student clarified the obvious confusion he has about anatomical structures of higher plants.

The second examination oriented question also arose from a teacher-initiated discussion and the question was used for clarification of a previously used term. The teacher's reply enlarged upon his previous comments and reworded the material so that it was more specific. The remaining three instances show attempts by students to clarify their understanding of specific issues. For example, this sequence developed when students were examining photomicrographs of water- and food-carrying structures in plant stems:

A: ... There isn't a variety of cell sizing. Quite uniform, it really makes the wood really quite nice.

Student: Is this from a pine?

A: This is a pine. I'm going to introduce some matching terms here. These cells in the xylem...

From the transcript it is apparent the student established relationships between previous statements and the photomicrograph that the class was examining. It is also apparent that the meaning of his question was either ignored or not understood by the teacher. As a consequence the equivalent of a one-word answer was given and then the teacher carried on with what appears to be a predetermined course. The other two student-initiated questions were treated in a similar way.

On the basis of the previous examples it is seen that student-initiated queries receive little emphasis and, despite being directly related to issues being discussed, they are treated as inappropriate. This conclusion is based on the manner in which the questions are answered. An outgrowth of the manner in which students' questions are handled is the perception that such questions are not an important part of the learning process. This may partially explain why so few students asked questions. A further implication of the lack of student-initiated questions is that students do not perceive themselves as being able to add significantly to issues being discussed. Students are passively receiving information instead of being actively involved in developing their understanding of biology.

The observations concerning student-initiated questions appear to contribute meanings similar to those previously discussed as to how biological knowledge is perceived and presented by the teacher. The manner in which student-initiated questions are handled provides another reminder that the teacher's purpose is to transmit information and the students' purpose is to receive it. Also the short, clipped answers indicate that knowledge is not subject to interpretation; instead correct, specific answers exist and to obtain an answer, all a student has to do is ask the teacher. The teacher's personal view is that knowledge is open to interpretation but the use of a convergent teaching style, that has a strong element of communication control, leaves the opposite impression. In the case of classroom observations the researcher received the impression that biological knowledge is exact and not subject to interpretation. Because of this impression the teacher is seen as an individual who transmits knowledge instead of a person who assists students in interpreting knowledge. The impression adds further to the expert-novice separation that was noted earlier.

2. Subject Perspective

(a) What, according to the teacher's definition, constitutes biology as an area of study?

The first guiding question of this section examines the teacher's definition of biology as an area of study. In this analysis the teacher's subject perspective is interpreted to be the predominant view of school biology that provides a focus for the material presented. When the lesson transcripts are examined, the structured arrangement of the subject matter becomes evident. The primary arrangement of the subject matter is conceptual in that it consists of a system of ideas. The organization of the material is on the basis of photosynthetic biochemical relationships. A secondary arrangement of the subject matter is also evident. The teacher's presentations stress the biochemistry of photosynthesis but they also combine it with the history of biology. These features are combined by presenting significant historical experiments so that biochemical concepts are illustrated. Besides presenting the biochemical concepts, the historical organization reinforces the idea that biological knowledge is gradually becoming more complex. The idea of complexity is achieved by indicating that as more experiments were done, they became more sophisticated and the ideas became more difficult to understand. For example, van Helmont's experiment is presented as being very simple whereas Calvin's work is portrayed as complicated and difficult to understand.

The previous observations are supported by the teacher's comments as evidenced by the following discussion.

B: Ah, now something that you have done, ah, in the class that I noticed was you made a specific point of teaching the history of biology as you went through that section. And do you normally make a practice of doing that?

A: I would say that on this topic I normally do.

B: Um, huh.

A: And on this particular topic, for some reason I emphasize it more than other topics. Ah, because the book presents quite a few men in the treatment of the subject and secondly I guess I find it an opportunity to see progression more clearly than in some other fields. Maybe just because I'm aware of it. But ah, you can see how ideas grow. Starting quite early and ah, and how they progress and become more and more complex and more complicated. And how the level of experimentation then becomes more complex as time passes. I think it is an opportunity to point that out. Whether the students get that I don't know, but I definitely was trying to say O.K., the first questions that were asked and the way they were answered was certainly different than the questions being asked now and the way they're being sought now.

B: Um, huh.

A: Starting off with simply growing plants versus radioactive tracing.

On the basis of these observations it can be said that the teacher's subject perspective is a conceptual arrangement of relationships that is taught by initially presenting relatively simple concepts which are gradually expanded. The initial concepts are used as a foundation and subsequent points are presented in greater detail until the teacher's understanding is discussed. The impression of a conceptual arrangement, which gradually becomes more complex, is illustrated by phrases such as "I find it an opportunity to see progression more clearly", "see how ideas grow" and "how they progress and become more and more complex and more complicated." These comments demonstrate a view of biology that moves from the simple to the complex. In order that the teacher's subject perspective is more easily understood it is important to examine the rationale that governs the presentation of biological knowledge.

(b) What is the rationale for the teacher's knowledge?

Observations related to the rationale of why particular knowledge is presented leads to the inference that the teacher's view of biology is strongly influenced by empiricism. This term refers to the idea that reliable inferences are generated through a scientific method that is based on observations and controlled experiments. Further, the probability of scientific knowledge is demonstrated by the principle of induction (Radnitzky and Andersson, 1978, p. 23). Since the teacher's view of biology is empirically based, his presentation of school biology relies on data obtained from observations or controlled experiments. During a validation discussion the teacher indicated that he was in agreement with this inference because his conception of the biological method follows the presentation of the scientific method provided by Arms and Camp (1979, p. 3). With an empirical point of view the teacher considers knowledge that is derived from the scientific method as being more reliable than knowledge which has ideational, or theoretical, origins. Since the teacher holds an empirical point of view, it is expected that his presentation of school biology will reflect this view. In the following example the influence of empiricism on a lesson is seen. In this example the teacher presented students with information about leaf structures that are involved in the movement of carbon dioxide from the atmosphere into a leaf.

> A: We would investigate now, is, how can a plant breathe but at the same time stay wet inside? Well I'd like you to carry out this exercise now, on your own and what I want handed in, in twenty-five minutes are two hypotheses. They are indicated, one, you only have to prepare... [one copy per lab group].
>
> Just to review what we've done. I was expecting that you'd make some observations. You were to observe what the plant uses for breathing. That is, you were to see pores and the guard cells accompanying them, which are involved in gas exchange in the plants. We can call these bits of information that you were picking out, data I guess. Or you can call them facts, if you were thinking of, of again bits of information. Now we are trying to work out an explanation for how a plant regulates its gas exchange. How it opens and closes

> those pores we saw. So from our observations we're trying to draw some tentative explanation. And this is what you were expected to write down. ...

From the post-laboratory lesson it is apparent that the intent was to have students generate hypotheses but specific observations were discussed instead. In the first validation discussion teacher "A" indicated that he changed the focus of the lesson from hypothesis formation to an explanation but he did not inform the students of the change in focus. The teacher is aware of the differences between a hypothesis and an explanation but his lesson did not convey this distinction to the students. Because of this oversight, the lesson makes a direct connection between observations and causal explanations by stating that observations and facts are identical and then implying that facts are used to form explanations. In terms of knowledge formation there are several messages contained within this material that observers perceive. Perhaps the most important is that an empirical method provides facts which cannot be disputed and they are used to form causal explanations.

(c) How is the teacher's view of high school biology reflected in the lesson material?

The last guiding question raises the point of whether the teacher's view of biology influences the presentation of the subject material. In examining the transcript it is noticed that specific sections indicate biological knowledge is intended for individuals who demonstrate a proficiency in the subject. An apprenticeship program is suggested because students need to have theoretical and practical skills if they are to continue in biology. A discussion of how sugar originated in higher plants illustrates this point.

A: Here we're saying if sugar must come from sugar how do you get the first sugar? Now I'll just leave that question dangling for you. It would take us back and we would say to the origin of life. Where did the first photosynthesizing green organism come from? How did it get started? And I really have no clear answer to that. We'll just leave the question. ...

> ... My question I don't have a good answer for is, well where did the first sugar come from? How was the machinery put in place to make that very first sugar, in the ah, very first photosynthesizing plants? And we'll just have to leave that. I shouldn't leave you with the impression there is no answer, there's no answers to that. There are hypotheses you might say, or there are, there are suggested answers to that question but I'm not prepared to ah, reveal or go over those with you.

The impression that is received is one of a teacher possessing knowledge but choosing not to share it with other individuals. During our discussions he stated that knowledge is public and individuals should have access to it at all times. This is opposite to the view that was perceived by the researcher. It appears the difference in interpretation depends on the phrase "but I'm not prepared to ah, reveal or go over those with you". The teacher stated that the word "prepared" had two meanings for him. The first was that he was not academically prepared to deal with the issue and if he pursued it the possibility existed that information may be misrepresented. The second meaning was that the topic was inappropriate because of time and course constraints. The teacher suggested that there was insufficient time to deal with the issue properly and other course material needed to be taught.

The researcher's perception was that particular knowledge is made available to select students at certain points in their careers. Because of this perception, biology is represented as a community that admits its members on the basis of an apprenticeship. The process begins in school where a student learns basic principles, techniques and standards that constitute the field of biology as defined by teachers. If a student is successful at this stage he is permitted to advance to the next level, that of a university undergraduate. The following quotation demonstrates the message of an apprenticeship program.

> A: ... Now what we're really pushing for are some details that are then, um, not, not part of everybody's high school educational experience. And I'm saying we're aiming this primarily at you people, say those who are looking for your matriculation. And then maybe a program in the sciences. And by the way, many Aluminum Bay students go on beyond high school into science. A very large proportion do so.

The ultimate stage in such a program is reached by individuals who become research scientists and deal with specific information. For example, Ruben was presented in this way. The comment, "but to some minds that is satisfying knowledge [Ruben's discovery that atmospheric oxygen results from plants splitting water, not carbon dioxide, molecules] and they [biologists] spend hours and hours and hours in the laboratory figuring that out. Ah, discovering it. I'm saying the question is not for everyone perhaps", presents Ruben as an individual with special characteristics. Associated with this view is the impression that biologists have specialized knowledge and it is not intended for everyone, nor will it be made available.

The previous discussion attempted to show that an elitist image of biology and biologists may be presented through classroom lessons and the knowledge that accompanies this view is seen as difficult to understand. One implication of knowledge is that it is meant for the initiated and if students are not at a particular level they have to accept many knowledge claims on faith. An example of students accepting knowledge claims on faith occurred when the teacher presented material on how sugar originated in plants. On the basis of the presentation students accept that an explanation exists for the origin of sugar. The students are not offered ways to evaluate the teacher's statements.

Particular assumptions about biological knowledge are suggested by the teaching of biology as a subject that is partially revealable. One implication is that various forms of knowledge exist and some of these are understandable by the average layman but others are complicated and only research biologists are capable of understanding them. Associated with the forms of knowledge are values. Knowledge based on common-sense is not valued as highly as knowledge that is discovered through empirical means. Complex, theoretical knowledge is valued most highly as evidenced by the teacher's description of biologists and their historical experiments.

The foregoing analysis indicates the teacher's predominant view of school biology is an empiricist's frame of reference in which certain conceptions of biological knowledge are included. The teacher's conceptual arrangement of school biology suggests that biological knowledge is composed of a set of abstract structures that can be distinguished so that logical divisions can be made. Connections between the divisions are readily apparent. Intrinsic characteristics provide a framework for knowledge within a logical division. For example, historical experiments in photosynthesis comprise a logical division and some characteristics that join these experiments are the group of problems themselves, type of data gathered within the experiments and the manner in which the data are verified.

According to the teacher's conception, nature exists in reality and biology is one way of gaining an understanding of that reality. To teacher "A" knowledge is a human creation, it is not an existential object. The connection between reality and knowledge is not a direct correspondence but individuals come to know the connection through empirical means. As a consequence biological knowledge consists of causal explanations of observed phenomena. Even though the teacher indicates knowledge is a creation of man he gives his audience the impression that it consists of stable objects. This impression is derived from the teaching mode that presents biological knowledge as specific information which is discovered by empirical means. An implication of this perception is that knowledge is being reified. Man is seen as a passive interpreter of the world and individuals who possess knowledge can inform those who are ignorant. Associated with this perception of objectified knowledge is the view that such knowledge is intrinsically valuable.

Teacher "C"

1. Pedagogic perspective

(a) What is the theme around which the teaching takes place?

The first guiding question provides a focus for determining the theme of teacher "C"'s lessons. An examination of the transcripts reveals teacher "C" uses the ideas of structure and function to explain major concepts of the nutrition subsection. The concepts explained are those of photosynthesis and then teacher "C" relates those concepts to other basic biological processes. The connection that is made between photosynthesis and other biological processes is done on the basis of energy transfer. For the teacher, structure and function provide a framework for the organization and presentation of basic concepts. The teacher's framework is demonstrated in the following excerpt where he was responding to a student's question concerning gas exchange in the roots of a plant.

> C: Well you see, --- a viable plant you have to have an organ system, an organ working with another organ, with another organ. So you have snipped them off, so you have a stem which could be an organ. The leaves could be an organ. So as an organism it's incomplete, alright? And for it to have any form of growth it would then have to take in more water. The best water absorbing type structures are roots. So therefore as a function it would like, therefore, at least to develop a structure that's going to look after it. I'll keep working structure and function at you guys until you understand it. Everything has a function because it has a structure and that structure is going to have a direct bearing on how that function is carried out. O.K.?

Contained within the excerpt is a message that a relationship exists between the parts of an organism and the function of the organism. The relationship involves the idea that evolutionary developments have resulted in organisms possessing particular structures and because of the nature of the structures they have specific functions. Besides the structures determining the general type of functions, the structures also determine how organisms carry out the functions. It appears the teacher is using a teleological argument or an argument from design (Hull, 1974, p. 103) to convince students that a basic explanation exists for biological processes. The statement, "Everything has a function because it has a structure and that structure is going to have a direct bearing on how that function is carried out. O.K.?", is couched in terms of goals, purposes and functions thereby giving the impression that an overall purpose governs biology. This argument was used throughout the transcripts and it suggests that particular events are determined by later events. When this style of argument and its implications were pointed out to the teacher he stated he was not attempting to argue in a teleological manner but he was concerned with "learning implications." He was "trying to present information so students can learn the biological knowledge" and he felt that the structure and function principle presented in this particular way accomplished his goal.

In the context of structure and function the teacher referred to the relationship on an organ basis while other excerpts referred to a biochemical or cellular organizational scheme. A message of this type indicates the teacher conceives of biology as a study which is based on grades of organization. This term refers to the biological principle that protoplasmic systems are differentiated and organized into compartment units (Hickman, 1961, p. 91). The principle involves the idea that organisms are an organization of units differentiated and integrated for carrying out life processes and this organization goes from one level to another as the evolutionary path is ascended. The levels or grades of organization are broken down as follows: biochemical, protoplasmic, cellular, cell-tissue, tissue-organ, and organ systems.

The connection between the teacher's organizational framework and the theme of photosynthesis is that structure and function are explanatory concepts that are applicable to biology as a whole. These concepts are used to explain the theme of photosynthesis. The theme was suggested in comments such as the following two excerpts:

C: ... Homeostatic, so that now something is homeostasis. That means it is going to try and control a certain level of materials in its environment. And these materials in the environment must be kept at a fairly constant level. One of those things, or I should say two of those things must be kept constant in the environment of a cell are going to be the gases involved. Those two gases that Heidi stated earlier are going to be carbon dioxide and oxygen. Most organisms are going to either consume the carbon dioxide in their chemical reactions. And if they're consuming carbon dioxide, they're probably using other materials, for example water and they'll be releasing oxygen. Or they could be, for example, taking in oxygen and releasing carbon dioxide. Now those are the two major processes of life. The building of the complex material which is the consumption of the carbon dioxide or making of sugar. Or the breaking down of the sugar molecule and the releasing of carbon dioxide as a by-product. So those are the two major gases involved. The two major processes using those gases are photosynthesis and cellular respiration. ...

... PGAL the end-product of photosynthesis can be used to make sugars, can be used to make plant fats, oils, can be used to make plant proteins with the addition of nitrogen. O.K., so all the components that we classify as organic can find their origin through the process of photosynthesis. Of course there are going to be some exceptions and those would be your chemosynthetic type of organisms. ...

In these two excerpts comments such as, "the two major processes using those gases are photosynthesis and cellular respiration" and "O.K., so all the components that we classify as organic can find their origin through the process of photosynthesis", suggest a theme of energy transfer in photosynthesis. Apparently the teacher is suggesting photosynthesis is a basic process which converts light energy into chemical energy for living organisms. Underlying the suggestion is a thought that the theme is important for students to understand because the relationship of energy transfer provides a basic concept which is common to biology. It seems this concept is involved in the organization of the lessons as well as being used as a basis for other concepts.

Although the course description indicates autotrophic nutrition is the theme of this section the teacher did not discuss chemosynthetic organisms. In a later discussion the teacher indicated that he did not do this because of a "time factor and the topic was less important." He based his judgement of importance on provincial examinations and the amount of material in the authorized textbook. In his words, "the language of the text indicates a few organisms undergo chemosynthesis, therefore the text has helped form my opinions." It is on this basis that he decided not to teach the broader concept. His position is based on two assumptions. The first assumption is that if a concept is important a provincial authority will examine it. The second assumption is that the author of the textbook is an expert and since he did not devote a lot of space to chemosynthesis it is not important. Included in the second assumption is the idea that a classroom teacher has no right to question the decisions of an expert because the teacher is not an expert in the subject area.

In summary, an unstated theme of energy relations is evident in the transcript and it provides a framework around which the lessons are presented. The statements of teacher "C" suggest that he views the unstated theme as a basic principle which students are able to use to make sense of other biological principles.

(b) What is the prevalent mode of teaching that occurs in the classroom?

The second guiding question focuses attention on the dominant teaching mode and allows questions to be asked concerning observed patterns. Upon examining the transcripts the dominant mode that was observed was a form of lecturing. This term refers to the traditional presentation of factual material by exposition (Beasley, 1983, p. 716). For example, a typical lecture begins with the teacher making introductory remarks and then continuing with a description (e.g. the structure of a leaf). In the first validation discussion the teacher noted the frame of reference for the lecture (leaf structure) was a confirmatory lesson for material that the students had been taught in an earlier course. Although the following example uses information that is considered common knowledge for many students, it is representative of the dominant teaching mode.

C: Now the cross-section of the leaf. At the top of the leaf

> you have a water resistant cuticle, a layer of epidermal cells, which is something like your skin, they're transparent, protective. There's a layer of cells just below that, which are the palisade mesophyll. The palisade layer they contain a large number of chloroplasts and that's where the process of photosynthesis will take place. ...

The introductory remarks of this lecture serve two purposes. The first purpose is to focus students' attention on important points that are going to be presented in the future. The second purpose is to bridge past material to that which is about to be presented. In this example the teacher connected previous concepts of gas exchange to the structure of a leaf and then related the combined information to the movement of materials in cells. Once the information was related to the movement of materials in cells the concept of the opening and closing of stomata was discussed. As such, introductory statements of this type provide a commentary on what has happened, is happening and will happen. By including these remarks the teacher is separating the official or testable lesson from the unofficial or untestable lesson. The official lesson becomes the points the teacher stresses through repetition, tone of voice, choice of words or other communicative devices. It is these points students perceive as the material that forms examination questions. The remaining material is considered the unofficial lesson. For example, the unofficial material consists of interesting asides that are not directly related to testable material. The separation of material has meaning for what students consider important and what they perceive as knowledge.

The focusing statements in the previous excerpt indicate that specific statements of leaf structure are important and they are considered knowledge. As mentioned previously, factors such as the choice of words and the tone of voice give extra meaning to the introduction. For example, the focusing statement, "I'm going to concentrate on the carbon dioxide intake of a plant and I'm going to show you how it gets into the leaf and also how the control of gas exchange is controlled by the guard cells", contains words that project certainty. The phrases "going to show you how" and "is controlled" convey the message that what is about to be presented is known with certainty. Certainty is also conveyed by the tone of voice. When vocal emphasis is placed on declarative phrases a direct message is transmitted. In this example the message is that the upcoming explanations are correct. By stressing the correctness of the explanations doubt is removed from biology. Doubt is removed because a particular theory for the regulation of stomates is presented as the explanation. The teacher's explanation of the mechanism of stomatal regulation is equated with a change in sugar concentration in the guard cells. The change in sugar concentration is due to photosynthesis and as a consequence changes in osmotic pressure open and close the stomata. This explanation is in agreement with that offered by Kimball (1975, p. 225) which is the authorized textbook for Biology 30.

Both the teacher and the textbook present one theory as the explanation and students are not made aware that some six theories are presently considered for this phenomenon. Each theory appears to have its own merits and demerits. By presenting one theory the teacher is removing doubt from biological explanations. The removal of doubt has meaning for how students perceive biology. One possible inference is students may view biology as providing specific answers because explanations are presented as certain. A second possible inference is that students may not appreciate that theories usually explain some observations but not others. By presenting theories as certain, students are not aware of competition among supporters of various theories, that theories are tentative nor the role anomalous results play in the development of alternate theories.

The distinction between the official and unofficial lesson is further enhanced by the teacher's questioning method. The teacher frequently begins and ends a lesson by asking questions which summarize essential points of the previous lecture. For example, the following excerpt is a series of questions posed after a lecture on the light and dark reactions of photosynthesis.

C: Harriet? Did I leave you back on the light reaction? You tell me, what's the difference between the light reaction and the dark reaction?

Harriet: ——.

C: O.K. Dark reaction works because it gets the energy from the light reaction. The light reaction only works in the light. Therefore if the light reaction only works in the light it provides the energy for the dark. The dark won't work unless it gets energy from the light.

Harriet: Why do they call it the dark reaction?

C: Because it doesn't need sunlight directly.

Harriet: Can I call it indirect light reaction? This is so confusing.

C: O.K. call it the indirect light reaction and on a test call it dark.

Student: ——.

C: No, no. Photosynthesis, which is the production of sugar takes place during the daytime. Right? When they're in the sun. Now there is the reaction of building these complex materials takes place in two phases. One we have energy and two we use the energy. And the use of energy is called the dark reaction. Now, this is the confusing part when you first start photosynthesis. Even if you have the term dark reaction so you'd expect it to take place at night-time when there's no sun. But it doesn't require sunlight directly.

Student: So they both happen at the same time then?

C: They happen at exactly the same time.

Student: If there is light, why do you need the dark reaction?

C: O.K. good question. If the light reaction and the dark reaction take place at the same time, which I said they did. The question was why if there is light, why do I need a dark reaction? Because if I have light I have the light reaction. What is the product of the light reaction?

Student: Um, formation of ATP.

C: Formation of ATP. What's ATP?

Student: Energy.

C: Energy. So the light reaction pumps out little packets of energy. So what are you goin' to do with the energy?

Student: Food. Use it to make food.

C: Use it to make food. Where is it making the food?

The questions that make up this excerpt are analyzed on two levels. On the first level, the statements have a meaning which deals with checking or confirming students' understanding of particular concepts. For example, the excerpt begins with the teacher asking Harriet a question. Such a question checks whether she understood the point that had just been made. Next, the student's response is evaluated and judging by the response of teacher "C" he decided Harriet's understanding needed correcting. Later in the sequence the statement, "O.K. good question." serves a dual purpose. One, it checks the student's understanding and two, it provides an editing function which carries a value judgement on the student's question. In this instance the value judgement is that the student is attending to a point the teacher considers important. According to the teacher he purposely uses this questioning style because it allows him to one "check understanding", two "make sure the rest of the class hears the answer", and three "lead students to the next major point."

On a second level, the excerpt is examined for the meaning it has with respect to what is considered the official lesson. The analysis is based on the assumption that when a teacher summarizes a lecture the summary reflects the important points. During a summary particular points are stressed and students interpret these points as the official lesson. The second level of analysis is shown in the student's questions. For example, the teacher stresses differences between light and dark reactions. Harriet's questions show that she has focused on these points and she is attempting to clarify her understanding of the official lesson. It is on this basis that students perceive the stressed material as important and they make a distinction between the official and unofficial lesson.

(c) What is the interest in the communication process?

The third guiding question provides a focal point for examining the degree of control the teacher exercises over the communication process. The transcripts reflect a teacher who controls communication within lessons by using traditional lectures and then summarizing essential points through a series of questions and answers. This manner of teaching controls the content and topical coherence of the lessons because student involvement is precluded. As an example of the degree of control the teacher exercises the following extract is offered.

C: Alright, photosynthesis has two reactions, the light reaction and the dark reaction. The light reaction can be broken up into two subunits. Can anybody name both of them? Both the subunits of the light reaction? Leslie?

Leslie: Cyclic photophosphorylation and

C: Can you give it all together and a little louder so that other people can

Leslie: Cyclic photophosphorylation and non-cyclic photophosphorylation.

C: Cyclic photophosphorylation and non-cyclic photophosphorylation. Very briefly Harriet can you tell us something about cyclic photophosphorylation?

Harriet: Um, it goes in a cycle. And ah, it does need light...

C: It's light that goes around in a cycle. Light is required. What was the last part of ——. Phosphorylation. Harriet, what do you mean by phosphorylation?

Harriet: It's adding phosphates.

C: It's adding phosphates. What normally is going to receive the phosphate?

Harriet: ADP.

C: ADP. What's the product?

Harriet: ATP.

C: ATP. O.K. can you go over it now, all the statements that you've said so far?

The lesson begins with teacher "C" focusing attention on characteristics of the light reaction. The characteristics were the body of the previous lesson and in this instance they also serve as a bridge to the present lesson. The structure of the teacher's questions and replies illustrate a technique that serves at least three functions. One function is to check whether students paid attention to official lessons in previous classes. This is seen in the questions that are posed and the manner in which students' replies are assessed. Apparently the official lesson of the previous class was the presentation of light reaction characteristics because the questions stress definitions of cyclic and non-cyclic photophosphorylation. The questions are considered common knowledge by the teacher because they repeat what the students received in class the previous day. By making this assumption the questions serve as a check on students' participation. A second function is to maintain control of the lesson. This is accomplished by the teacher initiating a questioning sequence which determines the points that are discussed. The reverse situation, where a student initiates a question, is usually not allowed by the structure. If the teacher encourages students' questions he loses the initiative and since such questions are unpredictable the content of the lesson becomes unpredictable. With student-initiated questions the teacher is obliged to acknowledge and respond but he no longer controls the discussion. Without lesson control the teacher cannot fully determine lesson content. A third function is closely related to maintaining control of the lesson's content. By maintaining lesson control the direction of the lesson is determined. In the previous example the teacher maintained lesson control and he was able to direct the lesson to characteristics of the dark reaction.

The teacher's influence over the communication process has meaning for how the researcher perceived the subject matter that was presented. The subject matter of official lessons was perceived as information that has been scientifically verified; whereas the subject material of unofficial lessons was perceived as information which the teacher considered speculative. The subject material also received less stress and it was seen as less important. A perception of this nature is attributed to the manner in which the teacher used communicative devices to stress information. According to the teacher experimentally proven information is considered knowledge and it is this type of information that he passes to students. The following extract illustrates the teacher's thinking on what knowledge is and what should be presented to students.

B: O.K., can you tell me what you consider to be biological knowledge?

C: Biological knowledge?

B: Or just knowledge in general. It doesn't have to be specifically aimed at biology.

C: Unfortunately, I guess we're just at a point in time where there's a tremendous amount of, I don't know, information knowledge being thrown at us. ...

... Like doing the starch test. You take iodine and apply it to a potatoe and almost every, every time it happens. So does that mean without a doubt, whenever I add iodine to something and it turns blue-black it's going to contain starch? You know, it's like...

B: Well, would you consider the starch test as fact?

C: I use it as fact. Yes and I would consider it fact.

The teacher's view of biology is perceived in a particular way by the researcher. The perception is based on the observed teaching mode and the teacher's conception of biological knowledge. The teacher is viewed as an individual who is aware of scientific findings and he transmits this information to students. One inference that can be drawn from such a view of biology is that students perceive biology as a method that yields experimentally verified results and the results are interpreted as knowledge. The following extract from a discussion with a student illustrates how she has adopted a similar view of biology.

B: And, you don't know... For example, if you were going to generate a problem how would you go about doing it?

Pat: Generate a problem? I'd probably look for something that wasn't proven. Just go from there. See what thing I could use in the experimental process and that kind of stuff.

B: And do you, do you have to go through a certain series of steps? And ah,

Pat: Just like we're doing today. You go through a series of things and then come up with your conclusions and observations.

B: Alright, and what happens? You say you go through a series of steps. Can you skip any of those steps?

Pat: No.

B: What will happen if you do?

Pat: Your results wouldn't be correct.

B: Why not?

Pat: That's why, they wouldn't be appropriate, they wouldn't be accurate to what you're trying to find out, eh? If the step wasn't important it wouldn't be in there in the first place. So it must be done in a certain order and it has to be done to get the proper conclusions. The conclusions that you're looking for.

Later in the discussion Pat stated that the experimental procedure was the scientific method. Pat conceives of the scientific method as a series of five steps. To her, biology is a way of applying the scientific method to obtain knowledge. Her conception includes the idea that if the scientific method is properly applied the resulting conclusions are true. Such conclusions are guaranteed because the method, in Pat's view, has an inherent logic. To her, conclusions derived from experiments are true and she interprets them as knowledge. Pat's view reflects a reconstructed logic (Kaplan, 1964, pp. 3-11) of biology. In her view there is a linear progression of clearly stating goals and systematically working through the scientific method until the results are verified. The effect of a reconstructed logic is to encourage a form of thinking that results in closure and surety.

The third guiding question also focuses on the degree to which student-initiated questions are encouraged and the meaning the questions have for communication control. The lesson transcripts show that students occasionally ask questions concerning the material being discussed. For example, the following sequence developed when the teacher compared gas exchange in leaves and roots.

Lawson: How come they [roots] have to get oxygen? How come in some plants they're supposed to sit in the water? Like when you just cut off a shoot [and place it in] water?

C: O.K. Alright, good question. If he's just taken a plant and he's talking about making a slip or something. Usually when you make a slip where would it be? Tell me how you go about making a slip? The process, that's not with a sewing machine, a slip from a plant.

Lawson: ——.

C: What would you do? You just basically told me.

Lawson: Snip off the plant.

C: And then?

Lawson: ——.

C: O.K. where are the roots of the plant?

Lawson: Still attached to the plant.

C: Still attached to the plant under the ground right?

Lawson: Ya. ——.

C: Right. Right. That's right. What you've done now by taking and placing the little slip in the water is bring the water in direct contact with the cell. Eliminating the roots.

Lawson: ——.

C: They don't necessarily need a large quantity of oxygen, because we don't have the roots. And any oxygen that's dissolved should be enough oxygen to look after the oxygen requirements of the cell. O.K., so by cutting that piece of twig off and putting it in the water you've eliminated the roots so you don't need the function of those roots anymore.

Lawson: Then why do you think there are roots?

C: Ah, well that's called differentiation. That's specialization and that's controlled by hormones. We'll be getting into that a little bit later. Maybe we could keep on going with this but it gets off track a little bit. So if we keep with gas exchange. That was a good question about gas exchange but the extension of the roots that gets us into hormone control. And let's get the gas exchange first and then we look up how [

Lawson: [I just thought that if they had enough oxygen to make roots [

C: [Well, you see...

The teacher encourages student-initiated questions but throughout the transcripts there are no direct requests for such questions. Consequently it is assumed encouragement came from a classroom practice that was in place prior to the start of the research. In the first validation discussion the teacher stated the encouragement came from a conscious effort to make "students feel secure in class, feel good, not intimidated." In his words, it is a "socialization process" and "acknowledging the student is more important than knowledge presentation." Whenever a student-initiated question is asked the teacher usually provides an editing comment. In the previous example the editing comment is, "O.K., Alright, good question." The comment carries a value judgement that the question is appropriate to the present discussion. As a result the value judgement reinforces the asking of additional questions. Lawson has taken the initiative in the lesson because his question defines the topic of the reply. Consequently, the teacher no longer has direct control of the communication process. The teacher attempts to regain control by specifying the topic and by posing a series of questions to Lawson. A technique of this sort is only partially successful because the teacher cannot completely switch the direction of the question and its topical coherence without causing offence. Once again Lawson establishes control by asking, "Then why do you think there are roots?". The teacher regains control by focusing on the topic and placing limits on the relevance of what can be said. The teacher's statement, "Maybe we could keep on going with this but it gets off track a little bit. So if we keep with gas exchange. That was a good question about gas exchange but the extension of the roots that gets us into hormone control. And let's get the gas exchange first and then we look up how", focuses on the topic and indirectly provides limits for future questions. Besides specifying the topic the focusing statements also differentiate between the previously noted official and unofficial lessons. In this example the official lesson is a lecture on gas exchange. Although student-initiated questions are encouraged by the teacher, he limits these questions to unofficial lessons. In this example the focusing statements carry the message that specific points make up the official lesson and student's questions should be limited to the official topic.

2. Subject perspective

(a) What, according to the teacher's definition, constitutes biology as an area of study?

The first guiding question of this section focuses on the teacher's view of biology. In this analysis the teacher's subject perspective is interpreted to be the prevalent view of school biology that provides a focus for the material presented. The lesson transcripts reveal specific information was presented. The subject matter was presented according to a view that knowledge of basic biological principles is necessary for students if they are to be aware of their surroundings. According to his view specific information that has been experimentally verified satisfies the requirement of suitable knowledge.

Primarily the lessons involve biological knowledge on two levels. The first level is a presentation of descriptions of photosynthetic concepts. Apparently the descriptions provide students with background information so that they understand subsequent explanations. The subsequent explanations make up the second level of biological knowledge. A combination of the manner of teaching and communication control give the impression that information gained by biological methods is certain.

The concepts and principles that make up official lessons match appropriate sections of three chapters in the provincially authorized textbook. Kimball, the author of the textbook, states that present knowledge of photosynthesis is the outcome of experiments performed, and theories created, over a period of 300 years. During the lessons the teacher's use of a reconstructed logic of biology suggests that experimental results are the source of biological knowledge. As a result of the textbook and the teacher's interpretation of information contained in it, students are presented with experimental results as if they are certain. In the teacher's official lessons doubt is removed and the subsequent explanations are perceived as certain. When the teacher ignores failed experiments, anomalous results, and misinterpretations, students are presented with scientific observations that match perfectly with experimental results. Any inferences drawn from the results include all available information. Biology is presented as a form of technology in which faith, aesthetic sensitivity, personal commitment and the ability to accept ambiguity is lacking. By presenting biology as a form of technology, students perceive the subject as value free and free of error. In a later discussion the teacher stated his presentation of biology stresses certainty because of educational reasons. In his words the presentation of biological knowledge should be "selective" because a positive example "speeds up learning time. It's expedient when we're not dealing with all the failures of the past." Apparently he believes efficiency is important in learning concepts and the introduction of negative results, anomalies and past misinterpretations prevents students from covering the course as it is described in the curriculum guide.

Teacher "C" misrepresents biology by ignoring negative results. Kuhn (1962, p. 140) states, "As pedagogy this technique of presentation is unexceptionable. But when combined with the generally unhistorical air of science writing and with the occasional systematic misconstructions discussed above, one strong impression is overwhelmingly likely to follow: science has reached its present state by a series of individual discoveries and inventions that, when gathered together, constitute the modern body of technical knowledge." Kuhn (1963, p. 349) puts forth the argument that such misconstructions are beneficial because students need to be trained for the normal science paradigm in order that they are capable of carrying on current research activities. According to Kuhn preconception and resistance to innovation are characteristics upon which the vitality of a research paradigm depends. In Kuhn's view, students entering a mature normal paradigm must be appropriately equipped with preconceptions and a sense of resistance to innovation. Judging from Kuhn's description of normal paradigmatic science and teacher "C"'s rationale for selectively presenting material, it appears teacher "C" operates within a normal paradigm.

The previous inferences are based on observations made during the lessons and comments made by students and the teacher. For example, in a discussion about the purpose of biology the teacher stated that he teaches specific information to students. The following sequence illustrates the teacher's thinking on this point.

B: Now if, if that's the case, what's the purpose of biology?

C: What's the purpose of biology for high school students?

B: Or just biology in general.

C: O.K., biology in general, specifically high school would be to take and give some information to students. In other words the study of learning period, is to gain as much knowledge as you can about a particular area and from that area you can progress into new fields. As it's very difficult if you don't understand or you don't have any knowledge at all about biology and for some unknown reason you're working around and you drop some iodine on a piece of bread it turns blue-black and you think you've discovered something new when in fact that's been around for a long time. So we're trying to give these, ah students some knowledge about life and biology that has been to a large extent, that has been proven time and time again. It's almost... Most of it's been considered fact at this particular level they are getting. ...

B: So that, ah in terms of the students you teach, you're trying to arouse their curiosity?

C: Also I want to fill them with some knowledge about some of the things that go on around them. About their basic body works, about, ah you know the reproduction of how a cell functions, about some of the different requirements for life, some of the basics that are going on in their body, that are going on around them constantly. In other words, just making them aware of their surroundings.

On the basis of these observations the teacher views school biology as a subject that consists of information statements. The phrases, "give some information to students" and "fill them with some knowledge", illustrate the idea that the teacher conceives of school biology as a collection of information and one of his major functions is to transmit the information to students. Consistent with this view of school biology is the teacher's view of nature which is described as a form of realism (Hospers, 1967). Judging from a discussion the teacher believes a real world exists whether a person perceives it or not. This real world is knowable because sense experiences provide a reliable source of information. In the teacher's words, "If one of the human senses can detect it, it's a little more believable." This view is reflected in the following discussion:

B: And you can't indicate to me your decision about that [what influences his decision on what he accepts as fact]?

C: No I can't. But if anything, because it [experimental verification] happens so often I put my trust... And I think that's what a lot of it is, is trust in other individuals.

B: O.K., ah

C: And continuing on from that, a lot of times when I give knowledge or information to my students what I say... They believe what I'm telling them is the truth because they, for a lot of cases, they believe me.

B: Now, O.K., in the case of those facts that you're giving students are they something man has created or um, do those facts actually reflect what's found in the world?

C: Yes, that's, that's the question. I think we would like to see facts, at least I'd like to see facts, as something that is already there and it's just something that's been discovered and analyzed, rather than have us create the facts or create the situation to come up with a possible explanation of why something happens. I would rather the facts be presented as something as there, that we finally discover but it was there all the time, rather than, you know, create something to satisfy our own quest for knowledge.

B: So, correct me if I'm wrong but I'm interpreting what you're saying as that ah, these facts that we've discovered do represent what is in the world. And through the various processes that we use in biology we end up identifying those or discovering them?

C: Um, huh.

B: Is that right?

C: That's the way I would interpret, that's the way I would like facts to be interpreted. That's the way I like to use facts. As if something is already there and we just discover them.

The teacher's conception of an independently existing natural world involves the idea that statements about natural objects are known to be true because sense experiences have been verified by biological experiments. The sense experiences perceive the physical world pretty much as it is and experimentally verified facts reflect what is found in nature. As a result of this view what is experimentally verified is considered knowledge and it has a direct correspondence with the natural world. A realistic viewpoint of this type has meaning for biological knowledge and how the teacher interprets such knowledge for students. Since the teacher interprets knowledge to be a direct reflection of the natural world, it is expected this message is transmitted in his lectures. The comment, "That's the way I like to use facts. As if something is already there and we just discover them.", shows that the teacher transmits specific information to students.

(b) What is the rationale for the teacher's knowledge?

A possible rationale for the presentation of particular knowledge in school biology seems to involve the teacher's view of the world and his conception of the scientific method. Examination of the transcripts reveal that the teacher's conception of the natural world is a form of realism. According to his view one way of obtaining reliable knowledge about the world is through the application of the scientific method. His comments give the impression that biologists apply the scientific method and because it is inherently logical and systematic, specific information is obtained. The apparent rationale is that students should receive this specific information. Included in this rationale is the idea that at the high school level basic information is important because it allows students to understand basic biological principles. In the teacher's view, such principles allow students to understand their surroundings.

(c) How is the teacher's view of high school biology reflected in the lesson material?

The third guiding question of this section raises the issue of whether the teacher's view of biology influences the presentation of the subject material. Upon examining the transcript it is noticed that the teacher presents specific information in his lectures. The lesson presentations are consistent with a view of biology that conceives of the subject as a method of gaining information about the natural world and such information is used to explain other biological processes.

The influence of the teacher's view of biology is seen in his lectures. For example, a short extract from the beginning of a lecture illustrates the idea that biological knowledge consists of applicable information.

C: ... The next little bit is just a bunch of facts that can be applied to gas exchange and that is kind of fill in some empty parts along the way. So the actual gas exchange parts of the plant are going to be the primary oasis areas which are bounding spongy mesophyll. And again that relates back to the fact that I keep harping at you is that a cell that is usually considered alive is going to be surrounded by a fluid.

Statements such as "just a bunch of facts that can be applied" suggest that biology is perceived as a technical method. An inference of this view is that knowledge exists outside of man and through verification experiments, biological knowledge is discovered. Associated with this inference is the idea that the scientific method is logical and systematic. Consequently any anomalous results are due to human error, misinterpretation or other extraneous factors. During the second validation discussion the teacher stated he not only perceives biology as neutral and value-free but he presents it that way.

In conclusion, the teacher's view of the world is that of a realist who perceives biology as a subject that uncovers facts about the natural world. To him, biological knowledge is an accumulation of objective facts and he gives the impression that these facts should be passed to students so that causal factors in biological explanations are recognized.

Teacher "D"

1. Pedagogic perspective

(a) What is the theme around which the teaching takes place?

The first guiding question provides a focus for determining the theme of teacher "D"'s lessons. According to the teacher's introductory statements the intended theme was the study of energy transformations as a basic biological principle of living organisms. The teacher's intent was to study photosynthesis as a representational form of energy transformations so that students become aware of the significance of the principles in relation to other organisms. In a later discussion the teacher stated that the intent reflected an aspect of his educational philosophy. He felt the teaching of basic principles was necessary so that students would be able to understand subsequent steps in the photosynthetic process. In this particular instance the basic principles involved energy transformations while the subsequent steps were the oxidation-reduction reactions of photosynthesis. The teacher also stated that there was a philosophical reason behind the teaching of energy transformations. The teacher's personal philosophy is: "for things to happen there need to be forces behind them to make things go." In the teacher's philosophy, a force accounts for all attributes of the universe, whether the attributes are motion, life or energy transformations. In discussing this point the researcher perceived it as being the more important or fundamental issue in the teacher's conception of the world. Associated with this fundamental belief is the idea that students should be aware of such basic "truths." For example, the following three excerpts, from the initial lesson, illustrate the idea that the subject of subsequent lessons is broader than the concept of photosynthesis:

> D: ... Now in introducing this, ah, I'm not going to call this photosynthesis. We have another title for this unit which I think much more indicates what we are discussing. And that is energy transformation. ...
>
> ... This law [first law of thermodynamics] says that matter can neither be created nor destroyed only transformed from one form to another and that includes energy. So there is a direct relationship between these two things. As we look at a living system, that system can make some transformations between energy and matter eventually and continue to live. ...
>
> ... O.K. and so the point that I make is, isn't it nice for us to be able to determine or use some other laws. That's why I say the jig-saw puzzle isn't complete. To apply some other laws and to say ya, life is a little more unique than these other laws [laws of thermodynamics] suggest that it is. And the key concept is this, that in order for you and I to exist we must take, from the surroundings, energy and use it. ...

An examination of the transcripts reveals an underlying thought that the living condition is unique or special in some way and the science of biology is unable to account for this condition. The idea that life is special is introduced when the teacher states "life is a little more unique than these other laws suggest that it is." The teacher expressed the special nature of life in a human context and by inference extended it to other organisms. On one level, the teacher is indicating that organisms have an ability to momentarily reverse the second law of thermodynamics, but on another level, there is a second message in the statement. The second message suggests a vitalist view of biology in which life originates in a vital force that is distinct from chemical and physical principles. A vitalist view is suggested in the following excerpt from a summary of the introductory lesson.

D: ... The third concept that made life unique, that was in this one-way flow of energy there is a unique condition where we cycled matter and we utilized energy to go up against randomness or disorganization and actually build things up. And you grow and that's the wrong way. That's not towards disorganization, you become more complicated. Alright, under natural laws... And you've probably had this explained to you a thousand times before. How many chances are there, according to nature, in which you can take all the parts of your watch, throw them in a box, shake it up, and when you open the box there's your watch?

Student: It should happen.

D: According to nature, that's not natural. That's not according to the second law of thermodynamics. Things don't get more organized they get more disorganized. But life is a situation where things do get more complicated. A human being is a very complex organism.

In the summary the teacher made the analogy that the probability of life arising spontaneously is similar to the chance that a watch is made by randomly combining the appropriate parts. An unstated assumption of the analogy is that if there is a watch, there must be a watchmaker. The analogy suggests that a vitalistic force is responsible for the living condition. In this way the teacher has introduced a force to the study of biology. Besides introducing such a force, the suggestion is made that the science of biology, as it is conceived by the teacher, is incapable of investigating such a force. This point became evident in a discussion with the teacher when he stated, "You know, I very much believe that the essential nature of life, or what makes something living is a spiritual dimension, that science yet hasn't understood. And whether we will or won't I'm not sure. But science doesn't have a grasp on what spirit is because it doesn't fit into our realm of understanding yet."

The introduction of a vitalist force to biology has meaning for the manner in which the subject is presented. With the teacher conceiving of a force that is beyond the investigative capability of biology, the subject is reduced to a descriptive study which attempts to provide rational explanations of observed phenomena. In the first validation discussion teacher "D" stated he was consciously aware of the vitalistic message he was presenting. In his words, "biology looks at how it [life] happens rather than why it happens. Theology answers the why questions." The teacher's view of theology further emphasizes biology as a descriptive study. He believes man will move toward a better understanding of nature and "we will eventually reach a total understanding of life but it may not be in this mortal life." His thoughts link biological understanding with discovering details of nature. A "total understanding" is implicitly connected to understanding the vital force and that is only accomplished in the afterlife.

On the basis of the teacher's introductory remarks it is concluded that the teacher views energy transformation principles as major concepts in the study of biology. Associated with this view is the thought that making students aware of a principle permits them to perceive a fundamental connection among organisms. The view of teacher "D" is interpreted to mean that he provides students with generalized concepts because they provide a learning structure for subsequent material. A second conclusion is that the teacher's conception of biology is strongly influenced by his religious beliefs. Because of his religious beliefs biology is seen in practical terms. To him biology provides explanations of direct observations or perceived relationships.

(b) What is the prevalent mode of teaching that occurs in the classroom?

The second guiding question focuses on the prevalent mode of teaching. The predominant teaching strategy is a form of lecturing in which questioning plays a part. The term "lecturing" refers to the presentation of material by exposition in which verbal information is usually given to students. (Beasley, 1983, p. 716). The verbal presentation is frequently accompanied by questions and written blackboard summaries. The teacher perceives himself as using a "lecture-discussion" format in which there is an equality of the presentation of information and discussion about the information. The teacher indicated the reason a lecture-discussion format is used is that "students need to be told things to stimulate a discussion." Contained within the teacher's rationale is Freire's (1974) idea of banking knowledge. The teacher's comment demonstrates that he views teaching as a process which deposits knowledge with students and later they are capable of calling on the knowledge in a discussion.

Patterns begin to emerge when the transcripts for a teaching strategy are examined. For example, a typical exchange begins with the teacher asking a student a question and then using that student's response as a starting point to present a lecture. In this example the process begins with the teacher asking Jim a question:

D: ... Alright, chlorophyll is a pigment. What's a pigment Jim?

Jim: Um, it is a substance that... I forgot.

D: Close, Jim. Lane?

Lane: Light absorbing molecule.

D: It's a light absorbing molecule. Absorbs all wavelengths of light except for? [4 s p] Green. There's evidence in that experiment yesterday. Where you take some light, shine it through a prism, split it into the various wavelengths. When he took the test tube full of chlorophyll and set it in front of the spectrum and the green was basically the colour that was there. Alright, if you look at the diagram you'll note the chlorophyll has four parts to it. Four rings to it, and then it's got a side chain that sticks out to the left there, it sticks out to the left you'll notice there's a fair number of carbons and hydrogens in that chain, twenty carbons. That side chain is called a phytol group. ...

The observed pattern involves a series of basic questions that are asked prior to a lecture. Apparently, such questions serve as an introduction to the lecture topic. In the previous excerpt the teacher posed a question which had an answer that was common knowledge to the students. The answer was known because the definition of a plant pigment had been taught in an earlier class. In addition to the students knowing the answer, hints were provided immediately before the question was posed. As such, preliminary questions introduce the lecture and permit the teacher to present material which contributes to the cognitive aim of the lesson. In this lecture the lesson consisted of a description of the biochemical structure of chlorophyll molecules, the function of particular chlorophyll atoms, and the manner in which specific wavelengths of light are absorbed.

The focus of the lesson was the molecular details of chlorophyll structure and function. Thus, a direct message is transmitted to the students. The message is specific; that is, detailed information is valued by the teacher. Later in the validation of this material the teacher agreed with the inference and provided a reason for teaching specific information. The reason referred to his educational philosophy of viewing knowledge as being heirarchically structured and students must learn the basics before they are able to conceive of more complicated thoughts. Besides presenting a direct message in his lectures, the teacher frequently made comments which referred indirectly to the theme of energy transformations. For example, at the end of the lecture the teacher summarized the role of light in photosynthesis and indirectly related the specific points of the lesson to the theme around which the lessons are based. Although the teacher makes direct and indirect references to the theme, students perceive details of the lectures as important and it is suggested they view specific information as biological knowledge. The teacher is in agreement with this inference for the majority of students. In his words, "most kids get stuck on the facts but the smarter students apply the information to new situations; therefore, they are thinking." An indication that specific information is considered important by the teacher is found in the following exchange. Immediately prior to the exchange the teacher had summarized the essential points of the light reaction. The exchange begins with a student asking a question about a specific detail of the flow chart.

Dale: Where does the water come from?

D: Where does the water comes from? The water you drank this morning? What do you you mean where does it come from? What's inside the cell? —— 90% more water. That's where it comes from. But it's a good question. You tend to always forget when we look at a two-dimensional picture on the blackboard that this is happening in an ocean. So I keep using the term, an ocean's made of water. That's exactly where it happens, in this huge body of water. ——. Any questions about this? [14 s p] You think you could reproduce that [flow chart of the light reaction] do you? ——. Jovita?

Jovita: ——.

D: It goes through the cytochromes and back to chlorophyll. Got it? Take a real good look. [9 s p] Do you want to get out a piece of paper?

Students: No! No! Let's, let's...

D: Take a good look. I'm real serious about suggesting that you should be able to reproduce that. That's called learning.

Jim: That's called [bashing

D: [That's called bashing it into your brains. Well take a real good look and I won't have to get a baseball bat out.

Jim: Might as well.

D: Anybody want me to walk through it once more?

Students: Ya. Ya.

D: O.K. What you see before you, besides a mass of shapes, is the light reaction. Photosynthesis, as we mentioned, there are two reactions, the light reaction and the dark reaction. Of course the light reaction requires light and it has two parts to it. One is non-cyclic photophosphorylation and the second is cyclic photophosphorylation. ... Chlorophyll a passes electrons to ferrodoxin. Ferrodoxin passes electrons to flavin, flavin passes electrons to NAD. O.K. one, two, three, four, five, six steps. Most of you know how to count to six. Six steps alright?

Student: Why don't you leave that part... I don't get that part where H_2O comes in.

D: This part up here?

Student: Ya.

D: When water is with its friends, water in the cell is constantly undergoing,... It's constantly involved in a reversible reaction, in a dissociation reaction. ... You will see this [light reaction flow-chart] again but it won't all be there. None of it may be there. That's how important it is. Take a good look at it. Any other questions about this? Judy?

Judy: When we put this on a test or something, would we have to explain um, what each thing does?

D: Well, let's... If you recall I really would like to give you an oral test ---. To begin I'd really like you to understand the concept. This is the specifics and of course any time you're explaining something, specifics often help. But ultimately you've got to know the basic concepts. What I'm saying is this, I may ask you to describe the light reaction in detail. Now you'd describe it in as much detail as you know. Starting with non-cyclic photophosphorylation and cyclic photophosphorylation as two processes that produce, respectively oxygen as a by-product, ATP and $NADH_2$. And the other one produces ATP. And all this serves to drive the dark reaction. Now if you can add all the specifics you're that much further ahead. All students should be able to get 60 [%]. Those who spend a little extra time get 90 [%] because they've learned the specifics.

Throughout this example the teacher's comments demonstrate that details of the light reaction are important for students to know and memorization of such details is considered learning. The teacher's comment, "I'm real serious about suggesting that you should be able to reproduce that. That's called learning." carries the message that details are important, they are a major part of examination questions and students who are capable of memorizing such details are considered to have learned an aspect of photosynthesis. An extension of the memorization of details is that the number of errors is an indication of the amount of learning that has taken place. Apparently the teacher judges students' abilities according to the number of errors they make. The last point is illustrated when the teacher states, "All students should be able to get 60 [%]. Those who spend a little extra time get 90 [%] because they've learned the specifics."

A conclusion that can be drawn about the manner of teaching is that despite the teacher indicating general concepts of energy transformation are most important, students perceive specific information as the material that is most often tested, therefore specific information is attended to. Further, the students considered specific information as biological knowledge. The researcher contends the teaching mode, with its stress on detailed information, leads students to perceive details as important and they conceive biological knowledge as consisting of empirically verified, descriptive information. During the first validation discussion the teacher stated he agreed with this conclusion but his philosophy of education was opposite to that of stressing specific information. The teacher stated he felt trapped by the system which tests for specific information. The dilemma appears to involve a realization that students need to score well on final examinations; therefore, they need to be taught what is tested. His dilemma is that if he teaches according to his philosophy he will be going against the system. He sees teaching according to his philosophy as damaging to the students' futures. On one level, the teacher apparently believes the teaching of specific information provides a basis on which subsequent knowledge is built, but on a second level he feels "trapped" by a system that stresses specifics. The teacher's dilemma appears to involve a theory of learning, a pragmatic realization that the memorization of specific information is not equated with learning, plus a realization that to a large extent the educational system controls what content is taught as well as how it is taught. Despite recognizing the element of control he maintains he is free to teach according to his conscience.

(c) What is the interest in the communication process?

The third quiding question examines how the teaching mode controls the communication process. The transcripts illustrate a teacher who primarily uses a lecture-discussion format and occasionally uses a series of questions and answers to present information. The lecture-discussions typically begin with a question to a student and the student's reply forms an introduction to the lecture. Once the topic is introduced, the teacher presents specific information. Occasionally the lecture is interrupted by the teacher, or a student who spontaneously asks a question. After such an interruption a content oriented discussion usually takes place. The following excerpt is offered as an illustration of this type of situation. The teacher is explaining how pigments absorb particular wavelengths of light. The explanation results in one student answering a question and another student spontaneously posing a second question.

D: ... Action spectrum for photosynthesis that actually shows that that is true but it also gives us other evidence that there must be other pigments also available. Now, well why don't we see these other pigments? Why don't we see their colours evidenced in plants?

Jim: We do. Especially in the fall.

D: O.K., the colours you see in the fall are the unmasking, so to speak, of the other pigments. Which simply indicates that we will talk, in this course, mostly about chlorophyll, that there is so much of this there that you just can't see the others. And as chlorophyll, as the molecule breaks down in the fall, it is broken down by enzymes, that unmasks the other colours that are there, so you are able to see them. So this is the one we'll talk about mostly, O.K.? Mostly because of its tremendous quantity. Because it is there in such great amounts. Ken?

Ken: Would it be possible that there are other pigments that would absorb light from other spectrums?

D: Is it possible?

Ken: Ya.

D: Ya, anything's possible. There's lots of things... Any time you go outside the realm of the visible spectrum you're unable to see things. You need light to see. That's all I'm going to say.

Notice, the teacher's question, "Why don't we see their colour evidenced in plants?", results in Jim's answer being used to continue the presentation. The question may or may not have been rhetorical but since Jim provided the response that was consistent with the teacher's thoughts the lecture continued with what appears to be a predetermined course. Edwards and Furlong (1978, p. 15) state that in classrooms there is a formalized allocation of speaking and listening roles and teachers manage classroom interaction so as to produce an orderly and relevant student participation. Since Jim was not nominated by the teacher to provide the answer, the usual interaction was violated. Because his answer furthered the lecture, it was permitted. Normally the teacher allocates a student who is expected to answer, but in this case Jim seized the opportunity himself. Occasionally the previous situation was noticed in other lessons.

This indicates the teacher allows students some control of the communication process. The opposite situation, of the teacher controlling communication, was seen when Ken asked "Would it be possible that there are other pigments that would absorb light from other spectrums?" The teacher's response, "That's all I'm going to say." demonstrates that he considers the question to be inappropriate at this time. The response reinforces control over the communication process and determines the next topic of discussion.

The last example is most representational of the transcript. The teacher's response serves an editing function because it conveys the message as to what is considered appropriate for students to ask. The message is that unless a question is directly related to the topic being discussed it is considered inappropriate. Another example of the teacher controlling the communication process was observed when a student was asked:

D: O.K., so would we experience a net change as far as the guard cell is concerned? [3 s p] Sam?

Sam: Um

D: Just a yes or no answer. Leave out the philosophy here.

Sam: Yes.

Immediately prior to this exchange Sam had suggested different explanations to phenomena that the teacher was explaining. The teacher's comment, "Just a yes or no answer. Leave out the philosophy here." conveys the message that Sam's previous divergent questions were not suitable. The teacher requires students' questions and answers to be within certain boundaries. The teacher terms his comment a "sudden control mechanism" and during the first validation discussion he indicated he employed such mechanisms for two reasons. The first reason was previously identified. The teacher considers part of the teaching process to be providing direction for students' questions and answers. The decision as to whether or not a question or answer is appropriate appears to be related to the teacher's short term educational goal. Since the teacher's short term goal is unstated, students are unaware of criteria that govern the applicability of questions and answers. Students are expected to learn implicitly whether their questions or answers are appropriate. The second reason is one of a time constraint. The teacher feels control mechanisms are necessary if he is to cover the externally set course of study.

A possible meaning that is contained in the previous examples of communication control involves the idea that relationships exist between the teacher and students. The information being transmitted by the teacher is that there is a proper role for students and teachers. A student's role consists of paying attention to presented materials, replying with appropriate answers and reacting in such a way that the teacher is able to evaluate classroom participation. According to teacher "D" another aspect of a student's role is to think. To the teacher, thinking involves a process where specific information is considered and through either induction or deduction a conclusion is reached. Once a conclusion is reached it is the student's responsibility to synthesize the information with their existing knowledge and then internalize the knowledge in terms of an ultimate goal. The teacher judges internalization of knowledge to have taken place when a student is able to recall the conclusion, paraphrase the logical connections among specific points and then apply the resulting knowledge toward a goal.

Teacher "D" perceives his role as interpreting biological knowledge and transmitting it to students. Another facet of the teacher's role is to create a situation which encourages students to think. According to the teacher this is accomplished by "providing a lot of information or questions and walk them [students] through the logical process. Or get a student to explain how he made the connections." In the teacher's view thinking is a logical process whereby conclusions are reached.

The teacher's conception of the teacher and student's role in the learning process has meaning for students' conceptions of biological knowledge. A possible meaning students may extract from such classroom teaching is that the teacher is viewed as a transmitter of a body of logical knowledge. Also such knowledge consists of specific information that is interconnected by conclusions and the knowledge is aimed at solving practical problems. In addition, hints are given as to what is considered appropriate student questions and answers, therefore part of a student's role is to adjust his/her perception of biology and biological knowledge so that he/her enters the teacher's system of meaning. Students who are adept at altering their conception of biology and thereby entering the teacher's system of meaning are considered, by the teacher, to have learned. In comparing the teacher's responses to Ken and Sam's input it is clear that Ken has learned information that is considered important but Sam has not.

The teacher recognized that he was altering students' conceptions to be more in line with his system of meaning. He stated the "system moulds individuals. To survive in the system we have to accept it." The moulding of individuals was accepted by the teacher because he views society as an ordered system in which individuals require order to survive. In his view it is necessary for the educational system to have students enter a teacher's system of meaning.

The previous excerpt illustrates that the teacher exerts control over student input by indirectly placing limits on what is considered appropriate. Besides controlling communication through his comments, the teacher also controls communication through the use of questions and answers. The following exchange shows a series of questions and answers about the source of photosynthetic energy.

D: Where did the sun come from? We don't want to get into that. It starts in the sun as far as you and I are concerned. Radiant dinner. You'll probably run out of space too if you're drawing as big as I am. ---. O.K. The sun radiates energy out into space. Part of that comes down to earth, O.K.? What happens to the energy that hits the earth? That enters the atmosphere? Terry? Whatever this energy is.

Terry: Some of it bounces back.

D: Some of it bounces back. Off of what?

Terry: Off the atmosphere.

D: Off the atmosphere. Bounces back into space. So it never does get to the earth. What else happens? Lise, what happens to some of the rest of it?

Lise: ---.

D: Some of it goes through the atmosphere. Causing molecules of the atmosphere to speed up, right? Very good. What else happens? ---?

Student: It hits the earth once it gets to it.

D: Some of it actually hits the earth, instead of being diffused in the atmosphere and begins to do something to the molecules of the land, the water. It speeds them up. What else happens to that energy? It's absorbed? Is that what you said?

Student: It's used by the plants.

In this typical exchange of questions and answers the teacher manages both the formation of the question and the elaboration of the student's response. Notice the teacher's original question, "What happens to the energy that hits the earth?", was not directly answered by Terry. As a result of Terry not providing a totally appropriate answer, the teacher's reply incorporates useable elements and then elaborates and modifies the response so that information is presented to the class. During the first validation discussion the teacher indicated this series of questions and answers is a portion of a logical sequence in which students are led from one conclusion to another. The teacher stated because the appropriate answer was not provided the sequence was broken and the students did not establish the logic associated with the conclusion. With the breaking of the sequence the teacher incorporated useable elements of Terry's answer in the next reply, expanded on those elements and continued with the lesson. This exchange of questions and answers illustrates how and why the teacher controls classroom communication.

Control of communication is possible because of the structure that is used. The teacher formulates the questions and then assesses and modifies student responses. A structure of this type automatically reserves every other speaking turn for the teacher. Through the use of such a structure the teacher not only determines when a student speaks but by managing students' replies, the teacher determines the topic and direction of the discussion.

The use of question and answer sequences, as well as lecture-discussions, controls communication on a number of levels. On the first level, communication is controlled when a lecture-discussion mode is adopted because the teacher assumes a role of transmitter of information. During the lecture phase students fill a role as receivers of information and any input on their part is automatically precluded because of the teaching mode. The manner of teaching presents the teacher as an expert who is passing information to students. On a second level, communication is also controlled by the teacher's comments because they provide boundaries for student input. When a teacher provides such limits one message that is conveyed is a discussion must fit the teacher's frame of reference of what is suitable. Consequently, students adjust their conception of biology and biological knowledge so that it is more closely aligned with the teacher's system of meaning. On a third level, the managing of questions and answers determines both the topic and the path of the discussion. It is concluded that students perceive biological knowledge as an object which is presented to them. Although the foregoing discussion demonstrates how a teacher is capable of controlling the communication process when a lecture format is adopted, teacher "D" also uses a discussion technique with the students. During the discussions students are allowed input and they may perceive themselves as occasionally contributing to the lessons.

Despite the teacher occasionally using a discussion technique the researcher perceived the teacher presenting the lesson material as a body of specific information. The information that is presented appears to be thought of as concepts which explain observed relationships and biological information which consists of verified experimental results. The connection between such information and concepts is that explanatory principles are developed to account for perceived relations among verified experimental results. A perception of this nature indicates that the teacher presents biological information as existing in nature and man uncovers this information by performing experiments. To illustrate this point the following excerpt from a lecture on thermodynamics is offered.

D: ... When we're playing around with energy transformations we have a bunch of pieces to a jig-saw puzzle, but we're missing some of the pieces. I know when I turn out my jig-saw puzzle it gets very frustrating when you can't find all the pieces. Because there is that beautiful picture but it's missing something right? And you get frustrated. And that's sort of the way you might feel about this unit at times. That some of the pieces aren't there and I'm sorry I can't give them to you because we haven't found them yet. But I very much think there are all the laws to let us understand this available if we can just find them. ...

The statement, "But I very much think there are all the laws to let us understand this available if we can just find them." suggests an image that man's knowledge of natural events is separate from himself. Contained within the statement is the idea that nature follows pre-set laws and if man is sufficiently clever at applying the scientific method he discovers biological information and principles which explain relationships among this information.

The third guiding question also examines the relationship between the prevalent mode of teaching and the manner in which student-initiated questions are handled. The transcripts reveal that students frequently raised questions about specific points as well as asking true questions. A distinction that is made between the two types of questions is that in the first case the questions were designed to obtain specific information from the teacher. The second type of question, or the true question, reflects a knowledge of not knowing (Gadamer, 1975, p. 325). Students pose true questions when they want to gain an understanding of some aspect of biology. The following two excerpts illustrate the two types of student-initiated questions. The first excerpt begins with the teacher requesting questions after he presented a lecture on chlorophyll structure.

D: Any questions about the factory? This is a little more detailed than what you saw in the film-strip. Are there any questions about the pathways?

Student: What did you say about the pathways?

D: We said the enzymes appear to be arranged in specific pathways. O.K.? That's all I'm going to say right now. We're going to look at... In order for a series of reactions to occur, then perhaps like an assembly line there needs to be a worker at each place in the assembly line ...

In this case, the student's question is one that clarifies a previous point and the purpose is to gain specific information for possible examination questions. Of the student-initiated questions this type is most frequent, but occasionally a student posed a true question. In the second excerpt the teacher was lecturing on absorption of light by various pigments when a student asked:

Sam: Ah, do we have any information that says maybe plants throughout their existence have become more adapted to these different colours?

D: Ah, getting into the realm of evolution and getting into the realm of theory and hypothetical explanations. Possibly. The answer is of course possibly, Sam. ...

Sam's question was spontaneous and not related to a potential examination question. It is generally related to the topic of light absorption by plant pigments but it reflects a genuine desire to know. By posing such a question Sam has taken the initiative, and as a result momentarily causes the teacher's lecture to go in a different direction. Since Sam was genuinely seeking information, his display of ignorance lost him the initiative. The teacher provided a response which regained lesson control and it was used to continue the lecture on plant pigments.

A comparison of the two types of student-initiated questions reveals the teacher frequently requested questions. Students usually responded by asking questions dealing with details of biological concepts and how the details related to possible examination questions. For these student-initiated questions the teacher provided specific information that included hints for the up-coming examination. In contrast, the true student-initiated questions were posed less frequently and the teacher's responses were general. The wording of such responses suggested true questions were not valued.

For example, the teacher's response, "Ah, getting into the realm of evolution and getting into the realm of theory and hypothetical explanations. Possibly. The answer is of course, possibly, Sam." suggested to the researcher that questions that are not directly related to the topic or those that do not have an equivocal answer are not encouraged. The teacher indicated that an interpretation of this nature was incorrect. As a teacher, he values student questions and responses and actively encourages them. The teacher stated that his response reveals his attitude toward evolution. The concepts of evolution are contrary to his religious beliefs and the statement reflects a personal bias.

The previous section indicates student-initiated questions are encouraged but they should be of a specific nature. Questions that are encouraged are those directly related to the lesson topic. These questions reinforced particular details that had been taught and provided hints for future examinations. A meaning that can be attributed to these observations is that the teaching style encourages particular questions which help present specific biological information. The teacher maintains he only discourages student-initiated questions in areas where he does not feel comfortable because of a personal bias. Apparently he states his biases about the curriculum areas of evolution and reproduction. Teacher "D" perceives biology as a discipline which is neutral and value-free and the stating of his biases is viewed as a method of maintaining objectivity in the presentation of lesson content.

2. Subject perspective

(a) What, according to the teacher's definition, constitutes biology as an area of study?

The first guiding question of this section examines how the teacher views biology as an area of study. In this analysis the teacher's subject perspective is interpreted to be the prevalent view of school biology that provides a focus for the material presented. The transcripts reveal a systematic arrangement of the subject content. The organization of the material is based on the theme that principles of energy transformations are basic to organisms and an effective way to understand these principles is to examine specific biochemical details of photosynthesis. Apparently, the teacher assumes knowledge of photosynthetic processes permits students to perceive the significance of generalized biological concepts. The primary arrangement of the subject content involves an introduction to the principles of energy transformation. An important aspect of the teacher's view of energy transformations, as fundamental biological principles, is how energy relations link organisms. Besides teaching the commonalities of energy relations among organisms, the teacher also introduces the idea that the living condition is special and biology is incapable of explaining it. The introduction of special attributes of life suggests a separation of life and biology. The separation presents the idea that biology is a study which describes natural characteristics of life. The separation also attempts to develop causal explanations of perceived relationships among those characteristics. During the first validation discussion the teacher revealed that after the experience of cooperating on the research project he now tries to focus on the descriptive aspect of biology and decreases the emphasis that he places on the special attributes of life.

The following excerpt, taken from the researcher's discussion with the teacher, is offered to demonstrate the teacher's conception of biology as it relates to life being a special condition.

B: O.K., so maybe I'll start in on some questions as I did with some of the students. And, ah one of the things I'd like to know is what do you consider to be biological knowledge. A nice easy question to start.

D: A nice easy question. Well, um any concept or fact, or information that pertains to living things would be considered to be biology. And I'll follow the definition of life.

B: O.K., now is that knowledge, whatever you're putting in there, is that a construction of man or is it a reflection of what we find in nature?

D: Well, since I don't believe that science has been able to determine what life is, the actual entity, our study of biology is focusing on the structures we call living and so all our facts and information simply revolve around, does a living thing, quote, live? And what makes it living, in terms of what it does. And we try to understand the functions of the parts and structures of that living thing but I don't think that knowledge really gets at what , at what you know, life really is. And I don't know that science can, as it is. I guess this is a little bit of my own philosophy in terms of my religious background. ...

On the basis of these observations the teacher's view of biology is a subject that is limited to description. The comment, "I don't think that knowledge really gets at what, at what, you know, life really is." indicates the essence of the living condition is beyond biology. As a result biology becomes a science of description. Later in the discussion the teacher was asked if he thought that biology was capable of going beyond description and he replied because of his religious belief it would only occur in the afterlife. Comments of this nature indicate the teacher's subject perspective is influenced by theological considerations. It is expected that such considerations play a role in the rationale that governs the presentation of biological knowledge.

(b) What is the rationale for the teacher's knowledge?

The previously observed theological considerations appear as a fundamental premise on which the teacher's view of biology is based. Biology is conceived as a descriptive science and it is on this basis the teacher develops a rationale which governs the presentation of lesson material. Observations related to the rationale lead to the inference that the teacher combines learning theories with philosophy of science for the presentation of biological knowledge. Given the premise that biology is only capable of describing natural phenomena, the teacher's philosophy of science is empirically based. This term refers to the idea that reliable inferences are the result of the scientific method which is based on observations, controlled experiments and inductive arguments (Radnitzky and Andersson, 1978, p. 23). The teacher gives the impression the natural world is knowable through the scientific method and verified, experimental results are a close reflection of what exists. Since the teacher's view of biology is empirically based, it is expected classroom lessons reflect this view. In a discussion with the teacher about the scientific method he stated "Um it was good. It was a good method.", but he feels that its structured nature limits creativity. In his words, "... If you do it [biological research] according to the scientific method you have the least amount of subjectivity and the greatest amount of objectivity. But that takes out an important part of the project. ..."

The teacher's belief that the scientific method yields certain knowledge is reflected throughout the transcripts. He states the positive point of the scientific method is "you either know or don't know at the end of the process if your knowledge is certain." The following three excerpts illustrate the idea that the scientific method yields information which is proven considered knowledge.

D: ... Oxygen, O.K., now that's basically the general formula for photosynthesis, right? It is a little more specific than that, quite a bit more specific. We haven't balanced it first of all and we haven't added a number of things to this line here and we haven't talked about how we found out this is in fact correct. ...

D: ... O.K., part of the reason for showing this [photosynthesis equation] to you ah, is that all those things I put on the blackboard are pieces of information that have been derived from experimentation. Just like virtually everything that we go through in this course is derived by experimentation. ...

D: ... O.K., now, how could you prove experimentally that in fact this is the way photosynthesis works? By that I mean water gets split. Yes, we have an example here but it isn't using water and isn't using carbon dioxide and so there is always that shadow of doubt that if we try it in this situation it's different than it may be over there. How could you prove this? How could you test this? Judy?

Judy: Um, in chemistry we're doing something on the radioactive stuff. You could...

The phrases, "how we found out this is in fact correct", "how could you prove experimentally that in fact this is the way photosynthesis works", and "all those things I put on the blackboard are pieces of information that have been derived from experimentation", convey a message that the scientific method is a source of certain information which is interpreted as knowledge.

(c) How is the teacher's view of high school biology reflected in the lesson material?

The third guiding question of this section considers whether the teacher's view of biology influences the presentation of the subject matter. Examination of the transcripts reveals the teacher conceiving of biology as a method which describes factual observations of a real world. The teacher's introductory statements on energy transformation reveal this conception.

D: ... There are some facts here that when we get into some biochemistry that will prove to be a little more difficult for some than others. I'll present it in a much different fashion than the text, because I think I have an easier way to do it. So what I suggest to you then, if you're going to read the text through, just read the first part to give you some of the facts. Once you get into the reactions, which is nine point six, the dark reaction, ---, nine point six and on... From there you might not read that so much. Listen more carefully as to what we do in class. ...

The predominant message in the introduction is; subsequent lessons deal with experimentally verified information and students are expected to establish relationships among that information so that they are aware of the significance of generalized biological principles. Contained within this message is the idea that as biological knowledge accumulates biologists are able to develop causal explanations of basic principles. This idea is consistent with comments made by the teacher when he was asked, what is the purpose of biology?

D: More and more, you know, as we uncover more and more knowledge, or as we think about more and more things and experiment we can... In terms of where we're at as far as science is concerned I think that, you know, the, quote, discoveries, you know, have been men who have taken a look at those things around them and began to put one and one together to come up with two. And, quote, begin to understand some of these eternal truths. Now, until you know the whole package you're not sure how they interrelate with one another. So, you know, we talk about laws that exist. Yet as we learn new information and or, quote, discover new laws, we find we can overcome, supersede, halt in a particular situation, you know,... I used the example of gravity, that it always exists. That doesn't change, but the effects aren't always the same if you change the circumstances.

The impression that is received is one of a teacher who is aware of the existence of basic, unchanging natural laws and he views the scientific process as a method which uncovers knowledge about these laws. An inference of this view is that nature is based on eternal truths and man is capable of partially revealing these truths by applying the scientific method. The inference means sense experiences are reliable and man's perception of natural phenomena closely reflects natural conditions. As a result of man accepting the existence of eternal truths that determine natural conditions, biological knowledge becomes sense experiences that are repeatedly verified.

The teacher's view of school biology involves a supernatural force that accounts for basic principles and the study of these principles is the foundation of biology. His view also includes the idea that empirical research uncovers pre-existing information. A conception of this type means biological knowledge is seen in an objective manner. With knowledge being objectified, man is presented as a transmitter and receiver of such knowledge.

A synthesis of the analyses and interpretations of teacher "A", "C" and "D"

1. Pedagogic perspective

(a) Theme of subject material

Underlying the three teachers' themes is a basic idea that energy transformations provide a link for living organisms. Although this concept is apparently understood by all three teachers, their lessons gradually move from this common starting point to where specific details of various biological processes are stressed. Teachers "A" and "D" stress detailed points of biochemical reactions in the process of photosynthesis. Their lessons involve flow-charts of oxidation-reduction reactions in which electron transfer pathways play a key role. In contrast teacher "C" addresses similar issues but he presents them through concepts of structure and function. His approach is less theoretical and less detailed.

The major point to be made in relation to the theme of the subject material is that the teachers apparently agree on the theme but they do not carry it through their lessons. Observations of the content of the lessons, the manner in which the content is presented as well as the teacher's conceptions of biological knowledge indicate they stress details at the expense of broad concepts.

(b) Teaching modes

The teaching modes of teacher "A", "C", and "D" are described respectively as recitation, lecturing and lecture-discussion. In each case the teaching mode is in accord with the presentation of specific details. Teacher "A" accomplishes the presentation of material through the posing of questions and handling students' replies. The essence of his instructional strategy consists of posing a question, accepting particular points of a student's reply and then elaborating on these points so that new material is presented. Teachers "C" and "D" employ a version of a classical lecture. Teacher "C" makes a distinction between material which is considered important or testable and that which is interesting but not as important. His manner of teaching is to present a formal lecture accompanied by notes for the material he considers important and then, adopting a casual question and answer format for the less important points. Teacher "D" employs a lecture - discussion format in which details of biological processes are presented by lecture. Following the lecture a discussion takes place where teacher "D" clarifies points and attempts to determine if students are able to reproduce the material presented.

With respect to this study, the importance of examining individual teaching modes is to look at how the teachers' conceptions of biology and biological knowledge are reflected by their individual styles. In each case the teaching mode presents the lesson material as a logical, coherent body of specific detailed knowledge that has gradually been discovered through the scientific method. That individual teachers employ a reconstructed logic of biology in their lesson presentations is a central element of the teaching modes. The first way a reconstructed logic is used is an individual biologist's work is presented as a series of stages which are joined by formal logic. That is, a conclusion associated with the first stage is

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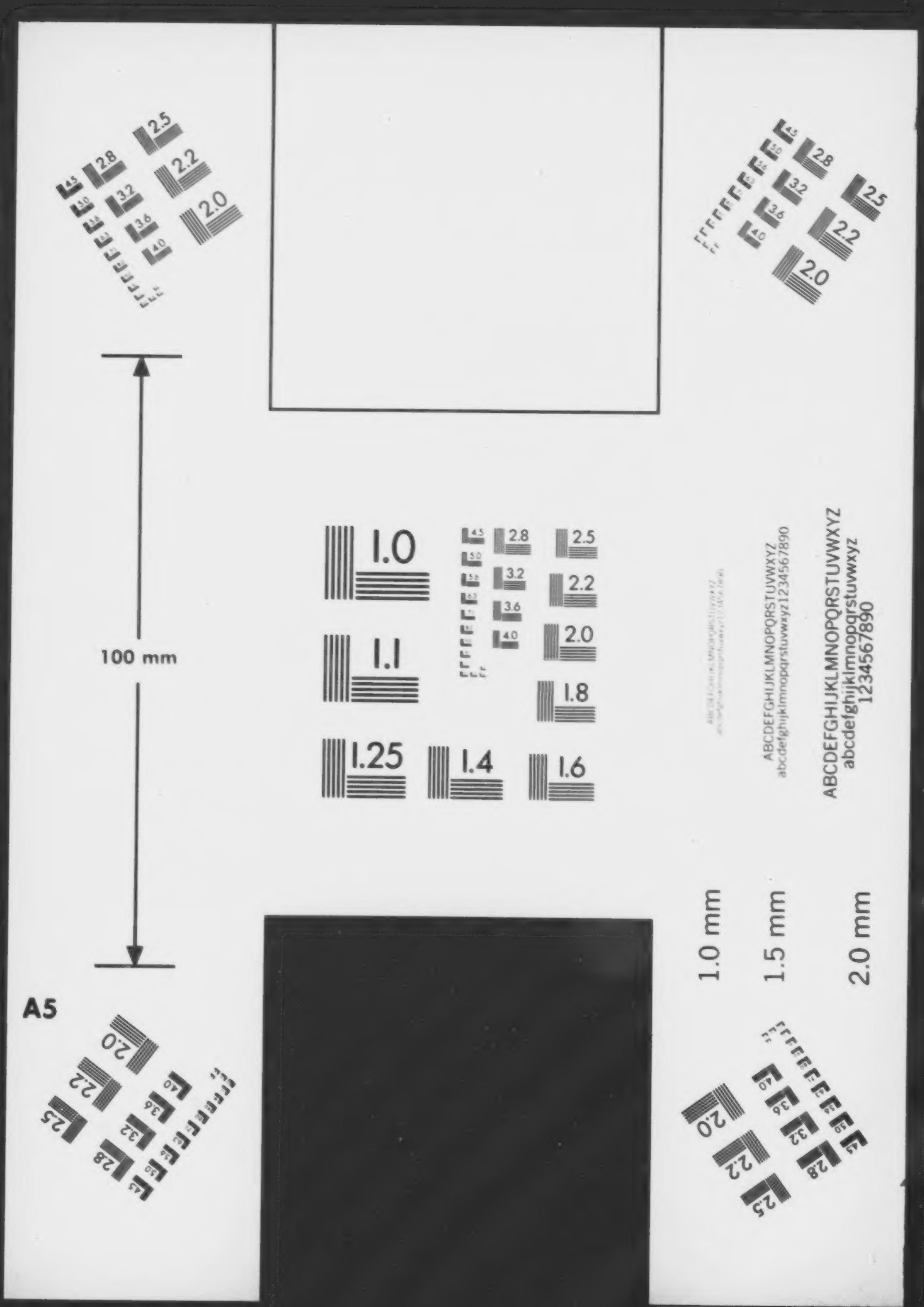

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logically linked to the second stage which is linked to the third stage and so on. The teachers then extend their reconstructed logic to the scientific enterprise as a whole. The work of one biologist is presented as a foundation from which the next biologist logically develops his fact, concept, law, theory, experiment or whatever. An implication of this style of presentation is that biology is conceived as a process which leads to a coherent body of certain knowledge.

(c) Control of communication

By examining the degree of control individual teachers exercise over the communication process the teachers' perceptions of classroom social relations are revealed. Teacher "A" exercised the greatest amount of control over the communication process, while teachers "C" and "D" occasionally allowed student input. It should be noted teachers "C" and "D" controlled the communication process for the presentation of material they considered important and they relaxed the process for interesting asides or unimportant points. It was during the relaxed phases students were allowed input.

When the communication process is examined the image of teachers and students that becomes apparent is one of experts and novices. Whenever the teachers were presenting material they considered of value, there was a distinction made in the roles of teachers and students. Teachers project the image of possessing knowledge and they are passing it to individuals who lack such knowledge. A student's role is to accept the knowledge and in teacher "D"'s words, "internalize it."

In light of the teacher and student roles, knowledge is being objectified and treated as a commodity. It is as if biological knowledge exists in the natural world and part of being a teacher is accumulating an appropriate stockpile so that it may be passed to students. An image of this nature indicates knowledge is not created by man but it is discovered. An implication of viewing knowledge as an object is students may conceive of biology as a process in which certain knowledge is discovered.

In the case of the three teachers the number of student-initiated questions varied widely. The number varied from a low of five student-initiated questions for the entire series of teacher "A"'s lessons to several per day for teacher "D". What was noticed about these questions? They belong to two broad categories. The categories are characterized as true questions and those aimed at clarifying a specific point about the lesson material. True questions are those questions that a student exhibits a knowledge of not knowing. This type was in the minority and it is interesting to examine the three teachers' approaches to them. With the students of teacher "A" there were no true questions observed during the seventeen class periods. Of the five student-initiated questions observed they dealt with future examination questions or points of clarification on the lesson material. Teacher"C" encouraged student questions but through communicative devices he indicated the points were not going to be tested; therefore, they were considered of less importance. Teacher "D" actively requested student questions and he provided detailed answers for questions closely related to lesson material. In the case of speculative questions teacher "D"'s responses were general and through his comments he tended to discourage divergent questions.

Comparing the three teachers' responses to student-initiated questions illustrates that such questions are encouraged if there is a close match between the questions and what the teacher considers important. One meaning this may have for students is that their thoughts must be specifically related to the teacher defined topic. This means speculation is discouraged while convergent thinking is encouraged.

2. Subject perspective

In the three analyses and interpretations the purpose of examining the subject perspective is to establish what each teacher assumes constitutes the subject as an area of study. Once the subject perspective is established, the next step is to examine each teacher's rationale as to why particular biological knowledge is presented. With the exposure of the subject perspectives additional questions are addressed that clarify the teachers' conceptions of biological knowledge.

(a) Biology as an area of study

Teacher "A" presents his conception of high school biology as collections of logically structured principles. It is a system of ideas concerning the natural world that are discovered by empirical means. There is a sense in teacher "A"'s conception that historical developments are important to an understanding of the discipline. Historical developments are involved in demonstrating the logical nature of biology. According to teacher "A" it is possible to examine experiments and trace a path of logical thought within experiments as well as from one experiment to another. Associated with the logical nature of the discipline is a notion of gradual development. He presents biology as a study which gradually accumulates knowledge and becomes more and more complex. The presentation of major experiments casts biologists as individuals with special attributes. Teacher "A" projects a sense that biology is a formalized process which yields a specialized form of knowledge.

In contrast, teacher "C" presents high school biology as a collection of information statements that he transmits to students. Teacher "C" accepts information from a variety of sources, determines what is of value in terms of educational goals, and then presents it to students. The basis on which the information is accepted as biological knowledge depends on whether the information has been experimentally verified. For teacher "C" scientific proof consists of repeated experimental verification through the application of controlled experiments.

There is close agreement between the teacher's conception of high school biology and the view presented in the provincially authorized textbook. The teacher employs a reconstructed logic that presents information contained in the textbook as if it is certain. Alternatives in the form of conflicting or discarded theories, anomalous results, misinterpretations or failed experiments are noticeably absent. Whenever biological experiments are discussed, there is perfect agreement between the observations and results.

Inferences that are drawn include all available information thus leaving students with the impression that biology is exceptionally neat, orderly and logical. Teacher "C" presents biology as a form of technology which follows a structured sequence.

Teacher "D"'s conception of high school biology is one of a structured system which describes characteristics of nature. His view of biology includes the concept that the process identified as the scientific method is the way in which biological knowledge is discovered. According to teacher "D" there is a natural world which exists in reality. Man perceives characteristics of that real world and through the process of the scientific method establishes statements which are considered certain knowledge. His view of biological knowledge is a correspondence view but it is limited to describing characteristics of organisms. Teacher "D" has a strong religious belief which introduces the concept of a vital force to living organisms, and therefore, separates biology from the study of life. To him biology is concerned with describing observations while theology deals with the living condition.

(b) Rationale for the presentation of biological knowledge

Teacher "A"'s rationale for presenting particular knowledge appears to be related to his conception of biology as a systematized method of studying nature which results in a formalized body of biological knowledge. Teacher "A"'s sense of biology as a discipline is more inclusive than just being a method. Once biological information is considered knowledge, it then becomes part of the discipline on which future knowledge is built. Part of the teacher's conception of biology is his view of the biological enterprise. The term biological enterprise is the system by which the study of biology is carried out. Teacher "A" conceives of the biological enterprise as an empirical process which closely follows the scientific method as identified in high school biology textbooks. The version of the scientific method teacher "A" referred to was an idealized version of the Baconian method.

Teacher "A"'s conception of the biological enterprise is based in empirical beliefs in which reliable inferences are generated through direct observations and controlled experiments. The teacher indicated that a process of induction is used to arrive at the experimental conclusions. If the conclusions are in agreement with the original observations and hypotheses the conclusions are considered reliable and therefore certain.

The teacher's conception of biology as a logically structured system and body of knowledge is the rationale for presenting particular knowledge to students. The content of the teacher's lessons is organized along historical lines and in so doing a logic is illustrated within an individual's experiments as well as a developmental sequence from one biologist to another. A commonality that is found in teacher "A"'s description of biologists' experiments along with the gradual development of biological knowledge is the idea the scientific method was applied in each instance. Associated with the application of the scientific method is a belief that the resulting conclusions are considered reliable. There is an unstated assumption that if the information is reliable it is considered certain and gradually it is conceived of as knowledge.

Teacher "C"'s rationale appears to be in direct contrast to teacher "A"'s. Teacher "A" gave the researcher the impression he was conveying a discipline to the students while teacher "C"'s rationale appears to be related to educational reasons. Teacher "C"'s view of the world is a form of realism in which the scientific method verifies a person's sense perceptions. His rationale for presenting particular knowledge to students is a pragmatic one. Teacher "C" believes students require biological knowledge if they are to function in and understand the world. His conception of biological knowledge appears to be closely associated with information contained in the provincially authorized textbook.

During the first validation discussion the researcher discussed with teacher "C" the three assumptions on which the analysis and interpretation was made. Teacher "C" agreed with the assumptions but he identified additional factors that he feels influence his presentations of biological knowledge. The first factor, according to him, is the course description as it is stipulated in the curriculum guide. The influence of the curriculum guide appears to operate on an legal and educational level. In terms of legality, the teacher gave the impression he was legally bound by the provincially prescribed course description, and thus he must teach all points contained in it. Although the teacher is apparently aware of the distinction between the curriculum guide (i.e., suggested activities or the course description) and the course of study (i.e., legal description) he left the researcher with the impression that he must follow the course description contained in the curriculum guide. An implication of the legal factor is that teachers feel they must present as much material as possible in order that they satisfy a perceived requirement. In terms of an educational influence teacher "C" indicated the curriculum guide specifies the teaching of particular topics that a teacher may either lack expertise in or does not have an interest in teaching. Because such topics are included in the curriculum guide the teacher perceives they must be taught and thus he is placed in a quandary. The quandary is that he perceives a legal requirement but he lacks the appropriate expertise or interest for the teaching of some topics. As a result the presentation of the subject matter is affected. The perceived legal responsibility forces the teacher to present the material he feels unprepared to present. One way the presentation of such material may be affected is the teacher relies on the textbook and thus students receive a narrow textbook interpretation of biology that reflects one conception of the subject.

To summarize, teacher "C"'s rationale for presenting particular biological knowledge appears to be directly linked to provincially prescribed requirements. He appears to conceive of his position as a dispenser of information. He collects the information related to the prescribed requirements and then transmits this to students without interpretation. This view of the teacher's rationale was reinforced when teacher "C" discussed how he presents his lesson material so that it closely reflects the material of the authorized textbook. The teacher indicated he was not an expert in biology; therefore, he could not question the content of a textbook nor the manner in which the information is presented.

Teacher "D"'s theological considerations influence the material that he presents as biological knowledge. The teacher's religious beliefs introduce a vital force to living organisms and thus he perceives biology as a science of description. As mentioned in Chapter III the question of vitalism is usually considered of historical interest. Hein (1972, p. 160) argues that vitalism is a historic controversy that is meta-theoretical in nature. That is, meta-theoretical concepts involve fundamental commitments on the part of their supporters which do not depend upon scientific evidence for retention nor will they be shaken by contrary evidence. Hein contends vitalism is such a concept and the supporters' commitments are based upon primary attitudes or "political" orientations which may have psycho-sociological explanation. She further argues these primary attitudes are not subject to rational justification. The supporters' attitudes determine what sort of justification is regarded as rational and, therefore, what sort of evidence is acceptable for the establishment of scientific conclusions.

Teacher "D"'s conception of a vital force is in agreement with Hein's position. The primary attitude of teacher "D" is that there is an essential dualism between life and matter and that he is mentally satisfied with the distinction. His comments that biology deals with "how" organisms work and theology deals with "why" they work demonstrate that he has established such a dualism. With the establishment and acceptance of a fundamental dualism biology is concerned with describing observations of reality. Teacher "D" accepts biology as an empirical method which permits individuals to describe the natural world. In addition teacher "D" conceives the Baconian scientific method as the structure by which knowledge is produced. In his view proper application of the scientific method results in certain knowledge. Consequently teacher "D" presents detailed description of empirically derived information to students. Occasionally he mentions the unique or special attributes of life but the content of his lessons is mainly description.

(c) Reflection of the teachers' conceptions of biology and biological knowledge in their lesson presentations

Teacher "A"'s view of biology as an amalgamation of a body of knowledge plus a discipline is conveyed in his lessons. He transmits the impression that biology as a science is somehow larger and more encompassing than just knowledge and a method. Occasionally during the lessons he provides instances of conflicting theoretical information or alternate explanations that convey the message biological knowledge is tentative. He also indicates to students that the scientific method is the most reliable way of knowing the world but it is not the only way. To illustrate this point he occasionally refers to theology as an alternative method. Associated with teacher "A"'s conception of the discipline of biology is the idea that it is in some way special. He presents biologists as individuals who have unique capabilities that are essential for understanding and appreciating many of the complex concepts involved in advancing the field. In this way he presents biology as a field that is open to selected individuals who deal with elitist knowledge.

Teacher "C"'s lectures suggest the idea that biology is a systematic, logical process that results in knowledge which is applicable. There is a pragmatic orientation to his philosophies of biology and education. He views biology as a way of gaining information about an individual's perceptions of reality and connects this philosophy of biology to an educational philosophy. In his view students live in the world; therefore, they need to know basic biological principles to exist in that world. His educational philosophy appears to involve a theory of learning that if detailed information is presented in small coherent packages and relationships are pointed out, students learn the appropriate fundamental principles.

The information he presents is conceived as being neutral and value-free because it is the result of the objective scientific method. He perceives the biological enterprise in this light and as a consequence also attributes the same characteristics to biological knowledge. In effect, he perceives knowledge as an end-product of a process which is free of man's influence.

Teacher "D"'s conception of biology as previously mentioned is based on a strong religious belief. This belief influences his lesson presentations because he views biology as a method which describes the natural world. The teacher conceives of objective scientific knowledge existing in the world and biology as one way of uncovering part of this knowledge.

Teacher "D"'s categorization of biology as a descriptive science has implications for his presentation of biological knowledge. By conceiving of biology as a study that is separate from the life condition the teacher implies biological knowledge is achieved by carefully but passively perceiving and studying the concrete aspects of reality. Once a perception is obtained a verbal description is generated which corresponds to the perception. The teacher is employing a correspondence theory of knowledge and by doing so he implies several things to the students. One, biology is a method that if skillfully applied uncovers biological knowledge. Two, biological knowledge exists as an object in the world. Three, a correspondence view of knowledge validly reflects reality. And four, biological knowledge is not influenced by factors such as the biological enterprise, culture or the individual biologist's interests.

In summary, the analyses and interpretations of teachers "A", "C" and "D" demonstrate they present the subsection of nutrition in three different manners, but there are many commonalities to the conceptions of biology and biological knowledge that are presented. There is a recognition of the importance of teaching the basic biological principle of energy transformation but it soon is replaced with the teaching of specific detailed information. All three teachers employ teaching modes that control student involvement. Student involvement is either limited to clarifying instructional matters or asking inconsequential questions. Teachers who encourage student-initiated questions have developed methods of indicating to the remaining class members that such points are unimportant and they are not considered part of high school biological knowledge.

The subject perspective that is presented by teachers "A", "C" and "D" varies, but they tend to conceive of biology as a method which follows the scientific method and ultimately produces certain knowledge. The three teachers employ a reconstructed logic in their lesson presentations. The use of a reconstructed logic presents biology as a completely logical, well-ordered science that employs the Baconian scientific method. Consequently, the teachers remove doubt, conflict and the creative elements from the science and present it as a technical method. Associated with a technical view is a perspective of biological knowledge which reifies such knowledge and conceives it as gradually accumulating over the history of the science. By considering biological knowledge as an object, the teachers present the image of experts who transmit information of biological discoveries to students.

B. Student analyses and interpretations

Introduction

The transcripts of the students' informal discussions are examined for points that reveal their philosophical positions of biology and conceptions of biological knowledge. Of the original eighteen student volunteers, five chose not to provide a second validation of the researcher's interpretation of their conceptions. Therefore, thirteen analyses and interpretations are included in Appendix G. The thirteen analyses are separated into three groups on the basis of perceived philosophies of biology. The first group has seven analyses, the second group, three and the third group, three.

Upon examining the individual transcripts, a commonality is observed about the students' conceptions of the discipline of biology. The commonality seems to be a focus on the biological enterprise or how biologists proceed in scientific inquiries. It is as if students conceive of biology as an activity. Usually the informal discussions centered on the technique or method employed in performing experiments but occasionally the domain and results were considered. Questions of value, science and society interactions and the tentativeness of biological knowledge were discussed but they were infrequently mentioned by the students.

Since the transcripts include points concerning the biological enterprise, the analyses and interpretations were based on this theme. In terms of the first group of seven analyses the philosophical position illustrated appears to be a modified version of the Baconian image of science. The second group consisting of three analyses, reflects a modified positivistic view of biology. The three analyses in the last group share a conceptual change view (Waterman, 1982, p. 12) of biology.

Description of students' modified Baconian image of biology

A description of a Baconian image of science was provided in Chapter III and the seven analyses in the first group employ a modified version of this image. The seven students' conceptions of the biological enterprise include a series of steps. For example:

(a) Through an open-minded search obtain data from all relevant sources;

(b) Develop a hypothesis aimed at explaining the phenomenon in question;

(c) Develop a series of controlled experiments, suggested by the hypothesis, to test the hypothesis;

(d) Examine the experimental results to determine if they confirm or disconfirm the hypothesis. If the results disconfirm the hypothesis return to step (b), develop an alternate hypothesis and proceed with the method;

(e) Results that confirm the hypothesis are considered facts and thus the hypothesis becomes a biological explanation;

(f) A similar methodological approach [steps (a) to (e)] is used to test a biological explanation and repeated verification of the explanation results in the formation of a theory;

(g) The method [steps (a) to (e)] is used to test a biological theory and upon verification the theory acquires the status of a law;

(h) Once again the method [steps (a) to (e)] is used to test a biological law and upon verification the law is considered certain knowledge.

The philosophical foundation for this modified Baconian image is a combination of elements from empiricism and logical positivism. Empiricism contributes the idea that a world of physical objects exists and statements about these objects are known to be true through sense experiences. The objects of the world are known to exist independently of perception and the physical world is perceived pretty much as it is. Therefore, knowledge claims of it are justified. In addition to the empiricists' realistic view of the world there is an inference that observations, hypotheses, theories and laws must be subject to an experimental test in principle before they can be proposed as elements of science. Included in this inference is the idea that experimental verification of hypotheses and so on, results in reliable inferences which forms the basis of biological knowledge.

An element of logical positivism that is included in the students' modified Baconian image is that the conceived method is rational. Implied within each step, as well as from one step to the next step, there is the principle of formal logic. The means for determining acceptable evidence as verification of a hypothesis is usually a process of induction. The students also infer the use of deduction when they argue returning to the hypothesis stage when the results of crucial tests do not verify the original hypotheses. The implied use of the two forms of formal logic is contrary to Bacon's original experimental procedure (Blake et al. 1966). Bacon conceived of the experimental method as proceeding without the use of hypotheses and without deduction, although in reality he used both hypotheses and deduction. The students also incorporate both hypotheses and deduction in their method and this is why their conceptions of biology are considered a modified Baconian image.

The students' view of the biological enterprise is clearly reflected in the analysis and interpretation of the informal discussions with Pat, Lynda and Debbie. Their view is the biological enterprise consists of a series of steps that must be followed in a strict sequence in which no step is skipped. To them the structured system is based on formal logic and information derived from the system is both true and certain. Tony's comments indicate he includes the idea of objectivity in the biological enterprise. To him observations may be influenced by a person's judgement but within the biological enterprise there is a self-correcting mechanism which overcomes subjectivity or when subjective results are reported other biologists disregard them. There is an implicit faith being demonstrated by Tony with respect to biology being objective. The idea of objectivity is internally consistent with the idea the structured system yields true and certain knowledge.

Both Pat and Susan's conceptions of biology reflect faith in the structured system. According to Susan the experimental procedure yields true information provided the procedure is carefully followed. To her anomalous results are recorded because of human error. She does not consider the possibility that the method may account for the anomalous results or that it may be incorrect. Susan's view of absolute faith in the structured system is an extreme position but similar views are reflected by the other six students.

In summary, the seven students who project a modified Bacon image of science conceive the world in terms of a realistic view and they believe applying a logically structured scientific method results in true, certain knowledge being uncovered. They demonstrate an implicit faith in their method providing each step is followed.

Description of students' views of biological knowledge who conceive biology in a modified Baconian image

Associated with the students' conceptions of biology are particular views of biological knowledge. The seven students who put forth a modified Baconian image of biology perceive information as existing in nature and by the application of their conception of the scientific method knowledge is discovered or revealed.

Generally, the group of seven students see biological knowledge as specific statements that describe observations of natural objects. They conceive of biological knowledge existing as an object in the world and the biological enterprise discovers such knowledge. Associated with this view is the idea that knowledge gradually accumulates. This means the students are separating man from the world, thereby viewing him an an interpreter of what exists. By viewing man as being separate from knowledge they do not perceive it as a creation that is influenced by culture.

In discussing the reasons why the students conceive of biology and biological knowledge as they do several points become clear. For example Pat stated the reason she conceived of the biological enterprise as a series of steps that result in certain knowledge is that her school experiences presented biology in that way. Pat indicates her view of the biological enterprise is strongly influenced by the confirmatory exercises she was required to perform during laboratory periods. In the case of Susan, Lynda and Jim they indicated their conceptions of biological knowledge are directly affected by what they are taught in biology class. Susan conceives of knowledge as discrete facts. When she was asked to provide an example of biological knowledge she stated "knowing the different blood types is knowledge", and "for me it came from Biology 20." Jim also conceives of biological knowledge as facts that are taught in class. In his words, "alright, well from class I know what carbohydrates were, what proteins were and how they're used in your body. Like the human body." Jim further indicated his ideas of science and scientific knowledge come mostly from teachers. When asked where his conceptions came from he stated "mostly from teachers, a lot of it from personal reading. I think the best one is the teachers, though." It should be pointed out that Jim was an exception to the other students in that he frequently read articles in scientific journals and made an effort to scan the weekly science column of the local newspaper. In addition he also frequently watched science programs on television.

In conclusion, the seven students agree with a logical scientific method which, in their view, results in certain biological knowledge. Their conceptions of knowledge indicate biological knowledge is not created by the human mind but it exists in the world. Their views tended to be absolute. That is, they conceive the biological enterprise as a method which yields objective, unchanging information that is true and certain. The informal discussions did not reveal a tentative conception of knowledge. Also there was strong agreement that their views of biology and biological knowledge were the results of concepts taught in biology classes as well as the manner in which the concepts were presented.

Description of students' modified positivistic image of biology

The analyses and interpretations of Judy, Kathy and Lawson indicate they conceive of biology in a modified positivistic manner. Feibleman (1972, pp. 27-213) outlines a scientific method which is in close agreement with the students' conceptions. The students base their view on an experimental method but they are not as rigidly bound by the method as the seven students who exhibit a modified Bacon methodology.

Feibleman indicates the following steps are involved in a modified positivistic approach:

(a) Make observations of a specific aspect of nature;

(b) Collate the data and propose a hypothesis, or generalization, by the process of induction;

(c) Test the hypothesis by a series of crucial experiments to obtain data which either verifies the prediction of the hypothesis or shows the hypothesis to be incorrect;

(d) Analyze the experimental data and accept or reject the hypothesis;

(e) Develop a theory on the basis of verified hypotheses and observed facts;

(f) By a process of deduction develop predictions and test the theory by a series of crucial experiments;

(g) If the theory is repeatedly verified it can be tested as a law through prediction and control of a phenomena. That is, once a theory is verified predictions are made about controlling an aspect of nature and upon confirmation the theory is considered a law.

The philosophical basis for the modified positivistic method is empiricism and logical positivism as previously described for a modified Baconian image. The essential differences between the two versions of the biological enterprise are found in the type of observations initially made, the procedure followed when experimental results are not in agreement with the original hypothesis, and an attitude involving the degree of certainty associated with the process.

The first difference between the two methods is the manner in which observations are made. Observations associated with the modified positivistic method are directed at a specific aspect of nature, thereby indicating a problem or question is directing the method. Associated with the directing problem or question are goals, intents and purposes which immediately introduce a human element to this form of scientific method. The second difference is how hypotheses are handled when experimental results do not verify the original hypothesis. With the modified positivistic method the hypothesis is rejected or modified when results do not support it. In the case of the modified Baconian version when a hypothesis is not verified a biologist returns to the starting point and develops a new hypothesis. There is an indication the original hypothesis and experimental results are not used as information for the formulation of the new hypothesis. They also intimate verification is total. Such a degree of absolutism is lacking in the modified positivistic method. The third difference is the students' attitudes to the degree of certainty associated with the process. With the modified positivistic method the students are less demanding the method be followed in a step-by-step manner but they are also are less confident of the certainty of the knowledge that results.

The three students who exhibit a modified positivistic method demonstrate the third point most clearly. In Lawson's case he recognizes that elements of subjectivity, intuition, and human error influence the biological enterprise but he maintains a faith in the ability of empiricism to yield biological knowledge. Kathy's conception of biology is also strongly influenced by empiricism. She incorporates intuition and interpretation into her conception and by so doing introduces tentativeness to biological knowledge. She is aware that introducing doubt to her conception of biology means the resulting knowledge is also questionable. At present her faith in the modified positivistic process is strong and therefore she accepts the ability of the system to yield valid and reliable knowledge. Judy's conception of biology is a method that results in applicable and non-applicable knowledge. Judy's conception of biology is a practical way to gain information so that problems are solved. She conceives scientific questions and hypotheses growing out of prespecified goals. Such goals are determined by societal problems. Judy holds the notion that biological knowledge is partially determined by the scientific community. She stated an element of consensus is involved in biologists accepting experimental results as knowledge. This is in direct contrast to the idea of the modified Baconian image where all verified experimental results are considered certain knowledge.

Description of students' conceptions of knowledge who conceive biology in a modified positivistic manner

The elements of a realistic view of the world are found in the three students' conceptions of biological knowledge. They conceive biological knowledge to be the result of the modified positivistic method in which the reality of the natural world is reflected in experimental results. Typically, they conceive of knowledge as information about nature or ways such information is discovered. The information is discovered by a research method which includes controlled experiments because it is necessary to verify an experimental result before it is considered knowledge. The three students perceive biological knowledge as gradually accumulating but they do not perceive it resulting in ultimate truth.

In regards to influential factors in their conceptions of biology and biological knowledge the three students clearly identified lesson content and the manner in which the content was presented to them. In the second validation discussion Kathy stated "As students, from the beginning of grade school, we are conditioned to believe that textbooks and teachers taught material which is thought to be absolutely true." In the case of Lawson and Judy they identified the lesson content from a Biology 20 and a Grade 7 science class , respectively, as influencing their conception of biology and biological knowledge. From these statements it can be seen students are presented with a view of biology which they accept as true because it is provided by teachers and textbooks. The students are conditioned to accept what is presented and not to question it.

In summary, the three students who conceive biology in a modified positivistic manner base their conceptions on aspects of empiricism and logical positivism. As such their conceptions of a biological method and biological knowledge are closely aligned with the students who adopt a modified Baconian image of science. The major difference in the modified positivistic view is the students are less rigid in a research method and they conceive knowledge as being more tentative.

Description of students' conceptual change image of biology

Waterman (1982, p.12) identifies a conceptual change theory of scientific knowledge began as an alternate conception of science in response to perceived difficulties in the empiricist, logical positivist and Popperian falsificationist philosophies. Waterman identifies Kuhn (1962), Lakatos (1970) and Toulmin (1972) as some of the major theorists in this area. Besides these individuals Polanyi (1962) and Feyerabend (1975, 1980) also contribute to the conceptual change theory.

One of the major criticisms of empiricist, logical positivist, and falsificationist theories of scientific knowledge is the ahistorical treatment of science and a disregard for the actual practice of scientists. The conceptual change theory attempts to overcome these difficulties by examining science in light of its historical record and presenting real-life activities of scientists.

The view of the world included in the traditional theories of scientific knowledge is a form of realism. The theories present a correspondence view of knowledge and thereby argue the link between the world and the mind results in a source of truth. The assumption of realism is that personal observation is a process of accurate perception of reality. Polanyi (1962, pp. 105-120) uses examples of Rubin's ambiguous picture 'vase or faces', mimicry in insects, as well as illusions to demonstrate how perception differs when an individual concentrates on the foreground or the background of an image. Polanyi suggests perception is not an accurate process by which the truth of reality is revealed. Conceptual change theorists argue that perceptions of reality are context bound. That is, observations depend upon theories and experiences.

A second major criticism of the traditional theories is the use of reconstructed logic as the rational method of science. Kuhn's (1962) work on sociological aspects of science, Toulmin's (1972) contention that rationality requires the substance of a discipline and Feyerabend's (1975, 1980) position that science is nonrational and messy all developed from the idea that there are other aspects to the rational method of science.

The concept of rationality in the conceptual change theory includes reasons for people changing their concepts. Kuhn (1962) suggests changes are revolutionary and individuals working within a paradigm tend to collectively question their beliefs and with a leap of faith replace their old beliefs with a new set of beliefs. Toulmin (1972) argues for a more evolutionary approach in which some beliefs are changed but others remain the same. Toulmin also suggests the change in beliefs occur rationally which is in contrast to Kuhn's position. Another element of the conceptual change theory is the way scientific progress is viewed. According to Lakatos (1970) progress involves the fruitfulness of a research program. If empirical content is expanding and new facts are anticipated, the research program is considered progressive. As such, progress is conceptual change and development.

The major points of the conceptual change theory of scientific knowledge are summarized as follows:

(a) Scientific knowledge is conceived as changing and evolving bodies of concepts and theories;

(b) The state of a discipline and other components of rationality provide criteria for choosing among hypotheses, theories and evidential claims;

(c) Theories are generated and selected by components of rationality instead of being directly derived from observed facts;

(d) Observations are influenced by what is known. There is not a direct link between observations and knowledge.

Three students, Allen, Joel and Paul demonstrate some aspects of the conceptual change view in their conceptions of biology and biological knowledge. The three individuals base their conceptions in empiricism but they introduce elements of human influence to the formation of knowledge. For example, Allen conceives the biological enterprise in terms of the scientific method but when hypotheses and theories are developed he indicates components of rationality other than formal logic are involved. To him, a biologist's judgement is a factor in theory formation as well as the acceptance or rejection of that theory. Joel also reflects the position put forth by Allen but Joel discusses it in terms of a biologist's creativity. To Joel the methods used in biology are partly created by the biologist and partly dictated by the question being investigated. He does not perceive the biological enterprise as following a step by step method every time. Paul's conception of biology is the most extreme position adopted by the students involved in the study. He introduced subjective elements of hunches and feelings to the discipline and maintained they were part of the scientific process. He indicated the subjective elements are involved in the formation of hypotheses, theories and knowledge. This point illustrates that Paul does not consider knowledge to be the sole product of verified experimental results. It appears his conception of biological knowledge is based on a common sense view of how individuals make sense of their world and function within it. He extends his common sense view to biologists and expects them to function in a similar manner.

Description of students' conceptions of knowledge who conceive biology in a conceptual change manner

Although the three students apparently share many of the attributes associated with a conceptual change image of science and scientific knowledge there is a tendency for them to conceive of biological knowledge as information verified by experiment. Despite their conceptions of biological knowledge being closely related to the previous two groups Paul, Allen and Joel indicate cultural factors influence knowledge formation. Paul and Allen are also aware that the introduction of cultural factors automatically removes certainty from biological knowledge because interpretation becomes a consideration.

In terms of the three students' conceptions Paul and Joel identified influences within specific science classes that affected their views of biology and biological knowledge. In these classes alternate ways of knowing and different aspects of the development of the scientific enterprise were presented. Paul and Joel stated the lesson content presented under the topic of "the nature of science" made them view science in a different way. In Paul's case he also identified outside influences such as Zukov's (1979) The Dancing Wu Li Masters, his religious beliefs and a conscious effort to weigh as many sides of an issue as possible before making a decision. Allen was unable to specify factors that influenced his conceptions.

In summary, the three students who exhibit a conceptual change view of biology conceive the discipline to be a human endeavour. In addition, they view biological knowledge as reasonably stable but it is subject to change. Also they believe what is accepted as knowledge is subject to interpretations by biologists.

An overall summary of the conceptions of the thirteen students indicates that the majority view biology and biological knowledge in a traditional manner. Biology as a discipline is conceived as a branch of science which employs a structured method to uncover facts of the natural world. It is further conceived that the knowledge revealed by the structured method is true, certain and it gradually accumulates. In contrast, three students incorporated elements of a theory that indicates the biological enterprise is not as structured as formally suggested in science classes. The same three students also indicated biological knowledge is culturally influenced.

CHAPTER V

THE ONTOLOGY OF BIOLOGY TEACHING

Introduction

Chapter V of the dissertation examines the ontological questions, "What is it like to be a biology teacher?" and "What is it like to be a biology student?" Because the dissertation looks at the nature of teachers' and students' conceptions of epistemological aspects of biology and biological knowledge, this chapter examines the ontology of biology teaching from both teachers' and students' perspectives. The first section of this chapter deals with the teachers' perspectives while the second section deals with the students' perspectives.

The philosophical grounding

Ontological questions are questions that deal with the nature of being and are grounded in existential phenomenology (Rothe, 1978, p. 28). This branch of philosophy has several premises as its basis. A major premise of existential phenomenology is man searches for meaning of life, mind and reality. Followers of this philosophy maintain that as man is a conscious, intentional being it is impossible for an observer to separate himself from the world.

The thought that man is both in the world and conscious of the world is reflected in Gadamer's (1975) concept of historicity and Schutz's (1962, 1967, 1970) analysis of the world of daily life. The importance of viewing man in this dual position is that a reciprocal influence exists between man and his world. Because man influences and is influenced by the world, he gives meaning through his actions. In an attempt to study the question, "What is the meaning of biology teaching?" teachers' and students' actions are examined. To assist answering the question individuals' actions are examined with respect to the four concepts of freedom, choice, practical reasoning and responsibility. Rothe (1978) suggests the four concepts link education and existential phenomenology.

1. Being a biology teacher

The situation within which a biology teacher exists has a bearing on his conception of teaching and it illustrates Rothe's first concept of freedom. Conditions imposed by a situation influence a teacher's conception of individuals. For example, one teacher described the school as being located in an "upper-middle class area with professional parents" and a student body which is characterized by "an above average I.Q." He stated "the guidance people insist the average I.Q. of the student body is equal that of first year university students." The teacher implies that his "academic teaching style" is a result of these socio-economic terms. To the teacher an academic teaching style is basically the presentation of information in which he "tries to get students to mentally make connections of three or four items." The example illustrates situational influences and brings out the concept of freedom. The teacher feels his freedom to teach in a particular way is controlled by his colleagues' comments as well as his own perceptions of the situation.

The second concept of choice is demonstrated in that teachers indicated they feel situational constraints on their freedom to select and present subject content. One teacher indicated his freedom to choose subject material was eliminated because the curriculum guide specifies what is to be taught as well as the amount of detail and the amount of time to be spent on particular concepts. Generally the teachers feel a moral and legal obligation to adhere to the course description provided in the curriculum guide. All three teachers mentioned "time constraints" when asked why they present certain concepts but not others. For example, one teacher justified not elaborating on a point by stating he was under a time constraint because there was an excessive amount of material in the curriculum guide to cover.

The preceding points are contrasted by one teacher's comment "When I close that [classroom] door the system does not control me. I can teach almost anything I want and hardly no one can change that." The comment demonstrates part of being a biology teacher is perceiving situational constraints on academic freedom but maintaining a false independence. In one case a teacher accepted the situational and governmental constraints passively and viewed biology teaching as transmitting information according to the curriculum guide and authorized textbook. The second teacher was aware of academic freedom but judging by the content of his lessons he never exercised it. The third teacher was mainly concerned with situational constraints expressed by his colleagues and he adjusted his teaching style accordingly.

The concepts of freedom and choice are related for the three teachers because each one's perception of being denied freedom means not being able to choose the biology curriculum. Instead the teachers conceive the curriculum as being imposed by an outside authority. The major decisions become the order in which the lesson material is presented and the manner in which the content is presented. The concept of choice has been effectively reduced to an irrelevant level. Biology teachers recognize the lack of curriculum alternatives and they perceive their position in the organization as lacking decision making power.

The insignificant decisions are justified by the teachers using Rothe's third concept of practical reasoning in which pragmatic, personal and situational motives play a dominant role. For example, the three teachers adopt different teaching modes, stress different subject content and two of them provide practical reasons for teaching biology as they do. During the first validation discussion one teacher stated he personally believes that biological knowledge is open to interpretation but he rationalizes his authoritative presentation of biological knowledge in terms of students' futures and his own personal career. The teacher rationalizes that students are competing for positions in post-secondary institutions and the work-force and the subject content needs to be as specific as possible so that the students have the greatest opportunity to achieve high examination scores. In terms of his career, he indicated a teacher's ability is judged by administrators on the basis of efficiency and students' final examination results. Implicit within this statement is the thought that teaching ability is measured by students' grades. A further implication is that if a teacher has aspirations of promotion he teaches specific examination related details in such a way that students' grades are maximized. These implications are consistent with the manner in which the teacher presented his lessons thereby showing practical reasons influence educational decisions.

A second teacher bases his conception of biology, teaching style and educational rationale in practical terms and removes the philosophical element. In discussing the purpose of high school biology the teacher's statement "What I'm trying to do is present ..., At the point when I'm presenting some fairly specific basic information, so that students will have some information to carry on." indicates he conceives of biology as a collection of factual information and his function is to transmit this information to students so that they are able to function within the world. The teacher reduces biology and biology teaching to practicalities. Within this reduction the teacher is implicitly rejecting philosophy of science as a discipline. The following excerpt from an informal discussion demonstrates his view of philosophy:

Teacher:	... I don't know, I mean we're getting into a lot of philosophy of science. I avoid that.
B:	You avoid philosophy of science?

Teacher: Ya, I avoid philosophy. Period.

B: Why is that?

Teacher: Because it is so uncertain. If everybody has their own approach ...

The excerpt reveals a teacher who believes the philosophy of science clouds biological concepts and it is easier to understand such concepts if they are presented as information which is not open to interpretation. The teacher's lessons reflect a view of this nature because his lesson material is presented as absolute. To this teacher the practical reasons of ease of learning and the necessity of students being aware of specific biological information are justification for conceiving biology as a collection of information and viewing a biology teacher as a person who simply passes information to students.

To summarize, practical reasoning enters a teacher's conception of what it is to be a biology teacher. In one case a teacher focused on personal reasons for his future career. A second teacher justified his choice of teaching mode and lesson content on educational grounds. The educational grounds included ease of learning and the necessity of students being aware of specific biological information. He views information presented in an absolute way as easier to learn and he also considers such facts beneficial to students. The third teacher justified his teaching mode through learning theories. He conceives his manner of presentation as assisting students to learn what is important.

Rothe's fourth concept, phenomenological responsibility, was not exhibited by the three teachers. The three teachers presented rationalizations of time constraints when confronted with justifying the choice of material presented. One teacher indicated the curriculum guide is to be followed in detail thereby implying it is impossible to teach all sections adequately. The second teacher indicated his preferred manner of teaching and conception of biological knowledge is different from that which he presents but because of situational factors he adopts a manner which ensures his personal success. The third teacher also justified his biology teaching by arguing he cannot go against the educational system's practice of stressing information because the students' grades suffer. The rejection of responsibility has meaning for being a biology teacher. One meaning is that biology teaching does not involve making significant choices because their freedom is restricted and they perceive their organizational position to be powerless. A second meaning is that biology teachers assign educational responsibility to outside authorities.

As a summary of "What is it like to be a biology teacher?", the three teachers present an image of a person who is controlled by outside forces. The description they project of a biology teacher is an individual who makes minor educational decisions amid a number of situational forces. The situational forces include a provincial authority which dictates curriculum content in excessive detail, an educational system which encourages the presentation of information for testing purposes, colleagues establishing expectations of students' abilities, and personal ambitions. The image of a biology teacher that is presented by the three teachers is a person who recognizes deficiencies in positions advocated by the situational forces but the individual biology teacher chooses not to act. Action is discounted because it is perceived to be at the expense of students, therefore, the teacher accepts the position imposed by situational forces. Another aspect to this image is the passivity that is projected. A biology teacher is presented as an individual who does not react to outside forces; he merely accepts them and presents biological knowledge in way that satisfies the greatest number of outside forces.

2. Being a biology student

Although individuals conceive of themselves as independent the extent of their freedom is partially determined by their situation. The students who participated in the study were in highly structured situations, in both an organizational as well as a physical sense. Organizationally the three teachers moved toward similar, if not common, objectives, used identical materials and engaged in similar activities to achieve their goals. In the three classes the students' activities were organized around explicit, unambiguous questions and in two of the classes confirmatory laboratory exercises were part of the teaching. Once again the laboratory exercises required students to answer specific, detailed questions in which there was little room for interpretation. The lack of freedom is demonstrated in this description of a laboratory exercise that was followed by a series of questions and answers:

The students were provided a worksheet describing a procedure to illustrate stomata closing and opening, respectively, when a wet mount of the lower epidermis of a geranium leaf was flooded with a 5% salt solution and distilled water. The worksheet instructed the students to develop hypotheses concerning the opening and closing of stomata under normal conditions. After the students made their observations a series of questions was posed by the teacher. The following excerpt illustrates typical explicit questions:

A: So these are guard cells and that will be a stomate. That stomate is a hole that can change in size. How did you change its size? Debbie?

Debbie: When we added the salt solution.

A: You added salt solution. And what happened to the size of the hole? It shrunk. I don't know if I have a photograph of that or not. Let's see. Would that be the way it would appear after salt solution? [3 s p]

Student: Maybe on the upper one.

A: Maybe on the upper one. Not the one in the centre?

Student: ——.

The question and answer sequence continued until the teacher had presented an explanation of stomatal regulation. Toward the end of the class teacher "A" indicated there are other theories regarding this phenomenon and suggested that some observations are in disagreement with certain theories. The students were left with the impression that the major points of the explanation are known with certainty; it is only the minute details that are in dispute.

The following excerpt from a student's validation remarks illustrates her perception of the lack of freedom in high school laboratory exercises:

> Pat: At the time of our discussion my biology background was not very extensive and in fact all experimentation in any high school level is done in a very orderly fashion. Students are simply required to carry out the steps that are provided by their teachers. I think at that time, I believed that experimentation was only done in this manner and conclusions were only in agreement or contrast to the hypothesis.
>
> On page (346 of Appendix G) you say that "any experimental results must be considered correct." This is proof of the experimental procedure I had been exposed to where the hypothesis, observations and conclusions are already known and I had simply to perform the steps correctly. From my view the results of the experiments were always correct because they were given to me before my experimentation ever began.

Her comments demonstrate that structured teaching modes and lesson content leave students with an image of biology in which hypotheses are clearly supported or rejected. Further, observations result in data which are completely used in arriving at a conclusion. Students never encounter extraneous data. The image of biology Pat formed is one that is ideal. Biological experimentation is directly linked to empirical verification in which the standards of validation are not in doubt. A sense of certainty is being projected throughout the discipline. This includes empirical procedures and extends to what is considered biological knowledge.

Student freedoms are removed by the organizational methods of teachers. As a result biology is conceived as a highly structured system dealing with empirical verification. The students are exposed to reconstructed versions of biology which become idealized. Associated with such an idealized version is a constant under-emphasis of disagreements about methodology, anomalous results, and other aspects of biologists' activities. Since students' freedoms are strongly controlled by situational factors, students within the three classes are denied choices. If being involves choosing and reasoning within a situation, students from the three classes are denied the opportunity of becoming biology students because their choices and freedoms are limited.

There are students who are perceptive, in retrospect, to the amount of control exercised by teachers in classroom situations. This point is demonstrated in an extract from a student's letter concerning the validation of the interpretation of her conceptions:

> Kathy: As students, from the beginning of grade school, we are conditioned to believe that textbooks and teachers taught material which is thought to be absolutely true. My idea of a fact is defined through the theory that the idea must be scientifically proven through experimentation. Unfortunately, scientists are liable for the interpretation of the results of the experiments he performs. Therefore, the results may have different interpretations if the experiment is performed by other scientists. Facts would be considered to be true only if the results of an experiment are universal, performed by many people.

Kathy's comment regarding conditioning is revealing because it alludes to an image of biology teachers moulding students' conceptions of biology and biological knowledge. During the informal discussion Kathy admitted she accepted biological knowledge as being valid because she did not consider doubt as an attribute of such knowledge. This means she accepted the material presented by teachers and textbooks as absolutely true and viewed biology as a method of yielding certain knowledge. For this to happen, Kathy was not presented an opportunity to make a choice concerning aspects of biology. It appears an idealized version was presented to Kathy resulting in a view of biological knowledge which is considered absolutely true.

As practical reasoning is concerned with choice and action directed toward an intentional act (Rothe, 1978, p. 31) it is apparent students' reasoning centres around learning specific information for examination purposes. The students' choices and actions are directed by teachers comments. For example, students conclude that the important information consists of details to be memorized as a result of these teacher's comments:

> ... I recommend strongly that that formula that you see there in front of you, that you commit it to memory. You must know that formula because that formula tells you an awful lot of things ...
>
> ... And I recommend strongly ... I'm not going over the structure of a leaf with you. I did one day very quickly. Make sure you know about the cuticle, epidermis, function of the epidermis, palisade mesophyll, spongy mesophyll, that there's veins composed of xylem and phloem tissue, lower epidermis, guard cells and stomata. Know the structure of a leaf. It's found on page 166 and there's a diagram there you should know. [27 s p] ...
>
> ... Any questions about this [14 s p]. You think you could reproduce that [flow-chart] do you? ...
>
> ... O.K. You should be able to reproduce that. O.K. Most, of you remember back to when we just began the whole course, I talked about being able, at the end of a day or at the end of a unit, start with the general concept and from there work your way down. ...

The teachers' comments influence students' perceptions of what is considered important. Frequently students repeat the concern about lesson details for examination purposes as Dick's questions show:

Dick: Ah, two questions. Ah, one, would it help when we study for the test to draw out the diagrams —— to each other? And if we do ah, is that the first question, a that's the first question. And if we do where would ATP and NAD come in on the dark reaction?

Since practical reasoning constitutes the meanings an individual gives to his situation (Jehensen, 1973), it is apparent students associate being a biology student with learning specific information for examination purposes. Students leave the impression with an observer that they are only concerned with examination results.

Rothe's fourth concept, responsibility, includes an element of being accountable for the choices an individual makes. In being a biology student there is a shift from being accountable for choices, to being accountable to a biology teacher. The shift is related to the lack of freedom and choice available to students. When biology teachers control the organization of the biology curriculum students' responsibilities are reduced to satisfying teachers' expectations. Students are expected to enter the teacher's system of meaning. Those who are capable of adjusting their conceptions of biology and biological knowledge to be in close agreement with the teacher's conceptions are considered to have learned. Students who adjust their conceptions do so by accepting a biology student as an individual who is intellectually responsible to a biology teacher. The shift of responsibility from making choices to being accountable to another person shapes intellectually submissive, passive students.

The preceding chapter was an attempt to examine the ontological questions of "What is it like to be a biology teacher?" and "What is it like to be a biology student?" The first section of the chapter established being a biology teacher is strongly influenced by situational factors. Generally, being a biology teacher involves balancing outside forces with a personal educational philosophy but it appears outside forces tend to predominate in decision making.

In summary, being a biology student involves accepting a position in which you become intellectually dependent upon a teacher for your conceptions of biology and biological knowledge. Students, who are judged successful by biology teachers, are individuals who give up their freedom and ability to make intellectual choices. Being a biology student includes submitting intellectually so that the teacher's conceptual scheme is accepted without question. Students are not consciously aware of being intellectually dependent until questions are posed which causes them to reflect on their conceptions of biology and biological knowledge. A conditioning process operates within biology classes so that students perceive their purpose as learning particular points of a teacher's conceptions.

CHAPTER VI

DISCUSSION, CONCLUSIONS, RECOMMENDATIONS, SUGGESTIONS FOR FUTURE RESEARCH AND PERSONAL REFLECTIONS

Introduction

In this chapter the major findings of the study are discussed in relation to three thesis questions. Some educational implications of the study are followed by recommendations for future research. The chapter and dissertation close with a section including a general summary, conclusions and personal reflections.

What are the teachers' and students' conceptions of high school biology?

Teachers

With respect to establishing the teachers' conceptions of high school biology the study involved the processes of observing, transcribing and interpreting classroom lessons as well as transcribing and interpreting individual informal discussions the researcher held with each teacher. The interpretations attempted to clarify individual teacher's conceptions of biology and biological knowledge.

Teacher "A"'s conception of high school biology is based in a philosophy of realism in which there is a direct relationship between what is perceived and what is known. To teacher "A" biology is a logical, structured process which examines questions arising from perceptions of the natural world. According to the teacher the process used in biological investigations is a Baconian one and the advantage is resulting knowledge is known with a high degree of confidence. Teacher "A" describes himself as a "Baconian" and he goes so far as to state that the five steps of the scientific method reflect his view of biology.

Despite the teacher's own perception of his conception of biology, observations made by the researcher indicate teacher "A" tends to conceive and present biology in a modified positivistic manner. For example, teacher "A" does not advocate a non-directed collection of all data prior to beginning the experimental phase of a research project. He indicates a biologist's observations are directed at specific aspects of nature. This demonstrates a particular perspective prior to the observation phase. Within such a perspective there is the idea that the selection of data is not arbitrary. The perspective permits the observations but it also conditions them. Teacher "A" argues for the tentativeness of knowledge derived from the scientific method. This point is counter to the Baconian image where confirmatory results are accepted as certain. Despite these subtle differences in teacher "A"'s conception his lesson presentations stress an idealized image of the discipline that is strictly logical, the research aspect is subject to empirical verification with no external influences, and progress is a linear process of gradually adding to previous discoveries. Teacher "A"'s lessons convey an image of a discipline which deals with complex knowledge and individuals who choose to be involved in the discipline have special attributes. Teacher "A" presents biology as a prestigious endeavour.

Teacher "C" bases his conception of high school biology firmly in empiricism. His view of biology is reconstructed from textbooks and confirmatory laboratory exercises performed during university courses. His perspective of the physical world closely matches Hospers (1967, p. 494) description of naive realism. Teacher "C" maintains an individual's perceptions reflect the physical world and the use of controlled experiments results in knowledge which is certain. Within the teacher's realistic view is the idea that an individual's sense-impressions are caused by the physical things themselves. With this firm view of the physical world teacher "C" conceives of biology as an empirical process which reveals characteristics of nature. His conception of high school biology is viewed more from an educational perspective than from a scientific perspective. For teacher "C" an important aspect of biology education is the idea students require specific information to understand their world. To him, biological information is revealed by the scientific method and his function as a biology teacher is to pass such information to students. Teacher "C" accepts textbook information in an acritical manner and presents it as if it were certain.

Teacher "C"'s lessons present a consensus theory of biology. His lessons lack elements of "disagreements over methodology, goals and other elements that make up the paradigms of activity of scientists" (Apple, 1979, p.89). The teacher's conception is limited to a reconstructed view in which attributes such as doubt, intellectual conflict, subjectivity and non-rationality do not play a part. Teacher "C" presents biologists as passive observers who employ a totally objective, logical method which allows them to deduce conclusions that are justified and thereby establish categorically true knowledge.

Teacher "D"'s conception of high school biology is based in empiricism just as the other two teachers' conceptions are, but teacher "D"'s rationale rests on a religious foundation. He separates fundamental questions of the living condition from biology and assigns those questions to theology. By doing so, biology is conceived as a descriptive science which employs a modified positivistic method. To teacher "D" the scientific method is a process which results in knowledge that is known to be certain.

Teacher "D"'s lessons leave the impression that a higher being is responsible for creating a series of unchanging natural laws and it is these laws that govern nature. This message infers that man is capable of describing attributes of nature by the application of the scientific method. In his conception of biology there is a strong sense of formal logic as he discusses the gradual movement from forming a hypothesis to the ultimate proof of that hypothesis. To him it is a necessary condition that each thought be logically connected to each previous thought. It appears the logical connection is a form of deduction. The rationality of such a position is reflected in phrases such as, "what I try and do in the class is go through with the kids the logical thinking process to solve a problem", "we try to walk through the process", or "anybody want me to walk through is once more?" The image of biology that is created by such comments is one of structured linear thinking which implies biologists doing the original work also thought in this manner. This form of thought illustrates teacher "D" conceives of biology in terms of reconstructed logic and his lesson presentations reflect this view. Structured linear thinking guarantees certainty and allows the teacher to rationalize and make explicit many aspects of biology. If the teacher is able to present the perceived logical connections of a particular biological development he is assured of the outcome and thus he objectifies biology. A deficiency in this form of reasoning is that it makes biology product oriented and presents biology as technology. What is lacking in a technical view of biology is the human element. By ignoring the human aspect of the discipline the teacher presents a nineteenth century positivistic view of biology.

Students

Modified Baconian image of biology

Seven of the thirteen students are characterized by conceiving of biology in what is termed a modified Baconian image. These students strongly identify with the scientific method that is frequently recorded in biology textbooks. Their conceptions involve a rigidity in terms of thought. They conceive biology as a branch of science which proceeds by a lock-step method that results in absolute certainty. They conceive biology as being completely rational. Their view includes an extreme standard of objectivity which arises from the students viewing biologists as passive, uninterested, detached observers who have a deep commitment to accurately reporting their observations of nature. Associated with the objectivity of biologists is an implicit faith in the scientific method. The seven students project an image that any errors or anomalous results are due to human influence. The scientific method is seen as error free.

Modified positivistic image of biology

Three of the thirteen students exhibited what is termed a modified positivistic image of biology. The three students' conceptions are empirically based and a version of the scientific method is used to gain information about nature. Their conceptions are somewhat flexible in that the scientific method does not have to be rigidly followed and they also indicate the resulting information is not completely certain. Judy was one of the three students in this group and her conception was extreme in that she viewed biology from a technical perspective. To her, biology was a process of answering practical problems. The other two students, Kathy and Lawson, conceive human elements such as intuition, subjectivity and human error are part of biology and biological knowledge but they tend to dismiss these elements as not having a strong influence on the discipline.

Conceptual change view of biology

Three of the thirteen students' conceptions of biology are characterized by a conceptual change view of biology. The three students, Joel, Paul and Allen present conceptions of biology that involve empiricism but biological knowledge is seen as constantly changing and evolving. The three students include in their conceptions the idea that biology is a human endeavour. To them the formation of knowledge is influenced by humans. Joel incorporates tentativeness and an element of judgement in his conception of the formation of biological knowledge. Paul and Allen also include subjective elements in their conceptions and suggest the biological enterprise is not necessarily the rational, logical process that it is normally assumed to be. They suggest factors such as politics, economics, and intuition influence biology and thereby affect what is accepted as biological knowledge.

In terms of a philosophy of biology, what are the teachers and students' conceptions of biology?

The seven students who exhibited a modified Baconian image of science have taken elements from the Baconian and logical positivist philosophical positions and melded them into a relatively consistent view of biology. The term "relatively consistent" is used because in discussing various points with students it becomes apparent they adopt a particular philosophical view of science for one issue but given another issue they adopt a different philosophical view. For example, Susan conceives of time flowing at a constant rate and not being subject to human interpretation. To her, space extends evenly and the universe travels in one direction at a constant rate. With respect to time, motion and space it appears that Susan conceives of the universe in mechanistic terms. Despite her mechanistic view of the universe she does not extend it to biological explanations. She tends to conceive such explanations in terms of biochemical relationships. There are no suggestions of overt mechanistic principles in her explanations. Some authors (Gould, 1984, p. 84) argue reducing biological systems to biochemical and physical relationships indicates a mechanistic view and they would consider Susan to be a mechanist.

The group of seven students adopted elements of the version of the Baconian image of science reported in biology textbooks. For example, three Baconian elements appear to be central to their conceptions. One, it is necessary to employ an open-minded search of available information so that a hypothesis is developed. Two, if the experimental results disconfirm the hypothesis it is necessary for the biologist to return to the first step and develop an alternate hypothesis. Three, if the experimental results confirm the hypothesis the results and hypothesis are known to be certain and they are considered biological knowledge. The logical empiricist view that observations are unquestionable facts about the reality of nature is included in the students' positions. In addition, the students share the idea that formal logic describes how scientists reason with data, hypothesis and theories. There is a sense that the form of the argument is essential to conducting a scientific investigation. Consequently formal logic becomes the central instrument for making inferences and it is the standard for comparing hypotheses and theories as well as establishing the truth of statements.

The three teachers and the group of three students who conceive of biology in a modified positivistic manner appear to stress a logical positivist position. They present biology as strictly a logical process in which the search for certainty is a top priority. The most important task for a methodology is the establishment of true scientific propositions (Radnitzky, 1981, p. 51). The establishment of truth is accomplished through verification. Frequently students suggest experience plays a positive role in verifying biological results. They implied, by an inductive argument, that the greater number of times a particular result is obtained, the greater evidence for considering the hypothesis verified and the results as knowledge. The form of logic the teachers and students advance for a methodology is induction. Hypotheses and theories are put forth and these are confirmed or denied by deductively derived crucial tests. Another feature the teachers and students include from the positivist philosophy is the idea of objectivity. They tend to conceive biologists as individuals who blank out their background and training so that observations are seen as objective. They further assume the methodology is objective, and any conclusions are rational and uninfluenced by biologists or nonrational procedures. Underlying the principle of objectivity is that with the accumulation of more and more knowledge biology comes closer to answering the questions of the field. Progress is seen in terms of a closer approximation of the discipline as an ideal science.

The three students who exhibit a conceptual change view of biology also incorporate some positivist attributes in their conceptions. Although there is an overlap the students are philosophically consistent in their answers. For example, the three students do not conceive biological knowledge as completely stable and unchanging. They tend to view biological knowledge as a collection of information that is established by the scientific method but they indicate with future biological developments the information will change. A second feature of their conceptions is that formal logic is not the only criterion for determining the validity of results and establishing connections between hypotheses and theories. The students include criteria of the state of the discipline, societal factors, logic and other components of rationality in their conceptions. A third feature is observations are not necessarily accurate. This means current knowledge may be based on fallacies. A fourth feature is the manner in which hypotheses, theories, and laws are developed and accepted. Their conceptions suggest various methodological components are influenced by various constraints and they are not necessarily induced from observations.

What are the teachers and students' conceptions of biological knowledge?

The seven students who illustrate a modified Baconian image of biology tend to conceive biological knowledge as information that is verified by the scientific method. Once such information is established it does not change and biological knowledge gradually accumulates. The concept of knowledge formation and certainty are closely related in that knowledge obtained from the early stages of the scientific method is less certain than that obtained from the later stages. For example, knowledge from a verified hypothesis is not as certain as knowledge obtained from a verified law. The students also conceive knowledge existing in the world and biologists employ a series of techniques which uncover this knowledge. They separate man from knowledge formation and consider knowledge to be an object. An implication of this generalized view of knowledge is that biologists obtain an image of the discipline through experimental procedures which means one day biological knowledge will be complete.

One teacher also conceives of biological knowledge as consisting of information which exists in the world. His statements indicate he conceives of knowledge as being certain and independent of man and he teaches this conception to students. To him, it is important that students receive information so that they are able to function in the world.

The students in the modified positivistic group along with the remaining two teachers tend to conceive of biological knowledge as specific information but they introduce ideas of tentativeness and a realization that knowledge formation is influenced by man. The three students indicate they are aware that biology is only one way of knowing but they indicate it yields knowledge which is more reliable than other forms of knowing. There is a tendency on their part to objectify knowledge but it is not as strong a tendency as that exhibited by the modified Baconian students. The two teachers state biological knowledge is a creation of man but their lessons definitely present knowledge as an object which exists independent of the mind. The three teachers also organize their lesson material so that biological knowledge is presented as an object which is gradually accumulating and becoming more and more complex.

The three students in the conceptual change group view biological knowledge as a product of the scientific method but influenced by man. To them, knowledge is constantly changing and is not certain. The human element removes certainty from biological knowledge because the concept of nonrationality is inconsistent with certainty. Their conceptions include ideas that knowledge is accepted by "mass approval", "faith" and "reasonableness". These ideas indicate knowledge is subject to interpretation and it is not seen as an object which is true.

General Summary and Conclusions

High school students' and teachers' conceptions of biology were examined through interpretations of informal discussions and classroom observations. The descriptive material suggests many new research avenues. Of specific interest is an examination of students' conceptions of biology at other levels.

The results of this dissertation have significance on a practical level. The study revealed teachers have particular conceptions of biology and their lesson presentations reflect their conceptions. It also revealed students hold a variety of conceptions and in many cases the students and teachers' conceptions do not agree. Because of these differences, conceptual variations need to be considered in curriculum design and teachers need to be aware of the conception of biology they stress to students. The dissertation is useful because it helps clarify philosophical and epistemological positions of both students and teachers.

The research method is based in a situational-interpretative mode in which transcripts of informal discussions and classroom events form the major source of research data. This type of research permits the students and teachers to register their conceptions instead of reacting to a researchers' conception as is the case in survey research. In a study designed to help clarify a number of conceptions it is important to consider the previous point.

The audio recordings of informal discussions and classroom events complemented one another. In many cases points were explained, commented on, or elaborated during the informal discussions thus providing clearer understanding of an individual's perspective. One element that was crucial to the study was the validation discussions. Preparing transcripts and interpreting them alone would have been inadequate. A difficulty in terms of this study was getting students to provide a second validation. As collection of data and the interpretation phase of the study extended over a twelve month period, contact was lost with five students. To avoid this difficulty a study of this nature should be started as early in a school year as possible and student interpretations should be completed as quickly as possible.

In terms of generalized results the three teachers conceive of biology in a modified positivistic manner in which a research method yields information that is certain. Their conceptions of biological knowledge are based on a philosophy of realism in which there is a direct correspondence between their perceptions of the natural world and what biology uncovers as knowledge. They also tend to objectify knowledge and present it as certain. The students seem to hold three conceptions of biology. The largest group holds a modified Baconian image of biology. Their conceptions are rigid with respect to methodology and biological knowledge. The second group of students hold a conception which is termed a modified positivistic view. To them, the biological enterprise depends on formal logic but knowledge that results is more tentative than those students who hold a modified Baconian image. The last group of students hold a concept of biology that is termed a conceptual change view. These students view biology as an endeavour that is constantly changing because theories change. They tend to view knowledge as a construction of man instead of viewing it as something that exists in the world.

In conclusion, the study helps clarify students' and teachers' conceptions of biology as a discipline and biological knowledge. It also suggested relationships between the students' conceptions and the predominate conceptions presented in biology classes. Approaches to future research on this relationship are suggested in this chapter.

Educational implications

The research in this dissertation is an examination of teachers' and students' conceptions of biology as a discipline as well as their conceptions of biological knowledge. Such a description is a useful source of data for teachers of biology as well as university based personnel who are responsible for biology teacher preparation. From the study it was found high school students frequently conceive of the scientific method as a source of absolutely true knowledge. Such a belief may be a hindrance to students accepting biological knowledge as tentative.

As well as the dissertation revealing the participants' conceptions it also discusses their conceptions in terms of a philosophy of science. Three positions of biological knowledge are presented in some detail and this information is useful to biology teachers in presenting other conceptions of biology. The study further suggests presentations of biology follow a positivistic ideal which is mainly ahistorical.

The dissertation provides a basis for teachers to stimulate a discussion on epistemological issues in biology. Teachers may indicate implications of viewing the world from particular perspectives and how those perspectives influence an individual's interpretation of biology.

Some of the ways the preceding suggestions can be approached include discussing significant shifts in the history of biology from a philosophical standpoint. Classes may examine biology as one way of knowing which influences and is influenced by other disciplines. Or it may be possible to develop tasks which challenge students' conceptions instead of presenting biology as a litany with teachers posing predetermined questions and students providing memorized answers. The idea of discussing conceptual problems in the discipline instead of merely presenting detailed facts appears to be compatible with Brouwer and Singh (1983, p. 234) who state "Instead of asking questions related only to the application of theory and its technological impact on society, some emphasis should also be placed on the reasons why some scientists, or other segments of society, felt that certain basic questions about reality were not answered satisfactorily by the theory."

Or the discussion might include suggestions made by Waterman (1982, p. 154-5). She suggests the following list of activities for teachers who are concerned with presenting different views of science:

(1) Develop activities which help students see science as an epistemological enterprise;

(2) Help students become aware that they have beliefs about scientific knowledge, and what those beliefs are. For example, distribute a short questionnaire on truth and proof in science; and

(3) Present different views of knowledge through discussion.

Another suggestion is to apply Kuhn's concept of normal science. This would have students learn an experimental technique, perform a laboratory exercise and then study the results. Next the student tackles a new but related problem by modifying the technique he previously learned. Once the second experiment is completed a discussion follows on normal science.

Recommendations and suggestions for future research

The participants' conceptions have been examined using a situational interpretative approach. As such, the questions addressed in the dissertation have been examined from one particular perspective. Therefore, no ultimate conclusions concerning the epistemology of biology should be based solely on the approach employed here.

The study indicates that the teaching of biology occurs mainly through expository methods in which specific textbook material is presented to students. The lessons are seen as ahistorical and logical, making the version of biology that is presented positivistic. It is on this basis that a recommendation is made that biology teachers become aware of the implications of teaching biology as a positivisitic endeavour. For practising teachers, this may be accomplished through journal articles and discussions at events such as conventions. Efforts should also be made to instruct biology student teachers in a variety of conceptions of biology. Further, the student teachers should be made aware of their personal views of biology.

A second recommendation is that biology teachers should develop curricula which permit high school students to clarify their conceptions of biology and understand that the discipline is only one way of knowing. As was observed during classroom visits, it is too easy to emphasize content and the memorization of specific information. The section dealing with conceptions of biology should stress discussion and not the presentation of specific information.

Biology teachers need to be aware of the implications their personal conceptions of biology have on the presentation of lesson material. A third recommendation is that biology teachers should consider their perspectives of reality and determine the consequences their perspectives have on their perceptions of biological knowledge. It was observed that teachers held particular views and they often coerced students into adopting a particular system of meaning. In some cases a teacher considered compliant students as those who learned and intellectually resistant students as those who did not learn. It is assumed that teachers who are aware of their perspectives of reality and conceptions of biology will recognize that there are a variety of ways of viewing the world and biology and they will not force a particular view on students. Instead of presenting one view of biology it is suggested that teachers and students explore a variety of conceptions of biology. The implications of adopting particular views should be discussed during such explorations. One point that should be considered is what form of biological knowledge results when a particular conception of biology is adopted.

The willingness of the participants to co-operate in a situational-interpretative study is seen in the massive amount of data collected. This indicates that the techniques employed permit individuals to present their conceptions of a discipline. This is perceived as a positive aspect of the research because students and teachers did not react to the researcher's preconceived conception of biology and biological knowledge. Since an approach of this style works in a research setting it may serve as a guide for teachers who wish to discuss similar issues in class.

Another positive feature of the research style was evidenced in the participants' reactions to the written interpretations of their conceptions. Generally, the students and teachers agreed with interpretations indicating the concepts of hermeneutics and sociolinguistics enable a researcher to study a phenomenon from a different perspective. With respect to the interpretations, the participants questioned specific points and the choice of wording but they agreed with the majority of comments that were made. After the second validation discussion some students indicated the research experience caused them to reflect upon their conceptions of biology and as a consequence alter their conceptions. This observation suggests a fifth recommendation: a research study be undertaken to examine the question of a perceived relationship between an individual's reflection upon his conception of biology and how his conception is changed.

The last recommendation makes a suggestion for a specific research study. Besides this specific study the dissertation also raised general questions about potential research areas in conceptual change. As mentioned in the Introduction, the dissertation is an attempt to clarify teachers' and students' conceptions in a particular section of the Biology 30 curriculum. As conceived, this dissertation is an initial step in the study of the epistemology of biology and some possible research topics are:

(1) Exploration of the phenomena of conceptions of biology in other areas of the Biology 30 curriculum;

(2) Exploration of teachers' and students' conceptions in other branches of science;

(3) How do students' conceptions of biology change over a number of years;

(4) What are the underlying assumptions of particular philosophical positions and how do the assumptions colour an individual's conception of biology?

(5) What social relations are implied for teachers and students who adopt a conceptual change view of biology?

Personal reflections

At the beginning of a graduate program a student is aware the investigation of a research question is necessary. This section is a reflection upon the events that have taken place during the incubation, research phase and writing of the dissertation. The points contained here are a combination of notes and reflections about the graduate program.

At the beginning of my graduate program I was exposed to philosophical ideas that are termed the conceptual change view of biology in this dissertation. In particular, Thomas Kuhn's arguments that science is misrepresented and misinterpreted caused me to reflect upon the manner in which I taught biology for some ten years. The process of reflection suggested I presented biology as I had been taught. I had seen biology as neutral, value-free and a source of reliable information. It was also conceived as rational and objective. In retrospect I had been taught, through grade school and university, a positivistic form of biology. Involvement in botany research projects reinforced this image because a small element of a larger question was explained to me and I was expected to carry out specific experimental procedures related to the overall problem. This experimental work coincides with Kuhn's description of normal science.

When I was developing a research question for the graduate program my first thoughts were of performing a quantitative study. In discussing my idea with my colleagues and supervisor their general reactions were not enthusiastic and caused me to reconsider. At this time I began to wonder, "What are students' conceptions of biology?" Once the question was formulated it received positive reaction from other individuals but I was uncertain how to study such a nebulous idea. Upon examining literature dealing with the question it became apparent little work had been done in the area and what work had been done was of a quantitative nature. Critiques of the quantitative studies indicated the researchers had students react to a researcher's conception of science and the studies did not reveal the students' conceptions. Based on this realization a qualitative research method was an obvious choice. Even though the choice of a qualitative method was a conscious decision I was apprehensive about the outcome. I foresaw myself collecting a massive amount of data and then being unable to analyze it. Also, I suppose there was a bias for technical research in which a statistical test could be performed.

Gradually, as the project progressed and a pilot study was undertaken it became apparent that informal discussions with students contain a great deal of information that cannot be gathered through quantitative methods. Arriving at this conclusion required a change of perspective and this carried over to observing a teacher's lesson presentations. A change in perspective allowed me to view the teacher's lessons from a point of view that questioned the individual teacher's conception of biology. Prior to that change in perspective I would not have considered a person's conceptions of biology as different from my own. Without a change in perspective the possibility of studying individuals' conceptions would not have occurred to me.

As the pilot study developed students' comments revealed their conceptions of biology were influenced by previous science courses and the students named specific events that were significant to them. In some cases the events had occurred five or six years earlier but they were recalled in detail. Within the students' comments were suggestions that their views of biological knowledge were associated with their conceptions. It was at this point I began to appreciate the power of informal discussions. If I had questioned the students with a survey it is doubtful the previous points would have been exposed because the survey would not have contained the appropriate questions.

My apprehension was quickly overcome because I now realized sufficient information would be obtained. During the research phase I was amazed at how readily I was accepted by the science department staff and the students of the three classes. Originally it was anticipated I would perform the research as an observer but the teachers and students draw you into a participant-observer role. The process of becoming a participant occurs gradually. Eventually you find yourself teaching students and acting as a resource person for the teachers. In all cases these functions developed because of requests by the students or teachers.

As the study progressed time became significant. The qualitative research style demands extensive amounts of time on the researcher's part. In my case the study involved three teachers and eighteen students and the research project was too large. Early in the research stage where the audio cassette recordings were being transcribed it was not uncommon to spend approximately fifteen hours to transcribe one hour of classroom discussion. This inordinate time commitment was needed to obtain an accurate transcription. Having a professional transcriber work on the recordings is unwise because of the difficulty in understanding what is said by the teachers and students in the classroom situations. Also a professional transcriber would miss information contained in voice inflections, pauses and other communication devices that is only available to an individual observing a situation and then listening to audio recordings of that situation.

The next difficulty arose after completing the transcription of first teacher's informal discussion and lesson presentations. As the transcription process was taking so long some members of the thesis advisory committee suggested I try interpreting the material for one teacher prior to completing the other material. An analysis scheme was developed and the first in-depth interpretation was completed. I met with the teacher and I was unsure of the type of reaction my interpretation would receive because I viewed it as being critical of the teacher's conception of biology. The teacher did not consider it critical with the exception of the use of one word and commented on the accuracy with which the interpretation captured his personal view of biology. At the end of approximately a three hour validation discussion I was reassured that it is possible to make a valid interpretation.

In making an interpretation of the second teacher's material I was again surprised by his reaction. His comments were very similar to the first teacher's. The second teacher required a more extensive explanation of the interpretation than did the first teacher. By the time the third teacher's interpretation was complete I expected it to accurately reflect his conception of biology.

Next, I listened to the tape recordings for the second teacher's lessons and identified themes. Once the complete set of tape recordings had been reviewed, I transcribed selected portions that illustrated the themes. This procedure was found to be successful and it was repeated for the third teacher. This technique of fully transcribing the first teacher's lessons and then only transcribing selected portions of the second and third teachers' lessons was beneficial in terms of time.

Once the interpretations were completed, analyzed and validated the writing of the dissertation was undertaken. After the writing of the dissertation was completed opportunities arose to reflect on the entire experience. In the case of the validation procedures it became evident that a significant source of data was missed by not having the students prepare written reflections on their experiences within the study. This point is raised because two students provided me with written syntheses of their views of school biology. Statements made by the students indicated they were taught to view biology in particular ways and their participation in the study caused them to question their personal view. Based on this observation researchers who employ a research approach that is similar to the one discussed in this study should consider obtaining written reflections from the participants.

Another issue that arose out of reflecting on the research experience was whether or not students would view biology form a conceptual change view if the curriculum was changed so that such a view was presented in class. The results of the study indicate that teachers present a conception of biology that is in agreement with their personal view. As a result it appears that students would be exposed to a conceptual change view only if the teacher's personal view was that of conceptual change. This means the prevalent view would become conceptual change and students would be unaware of other views. The limitation that was built into the teachers' conceptions was they they were not consciously aware of their personal view and apparently they did not realize their presentations conveyed a particular view to the students. As a result it is suggested that merely altering the curriculum so that a conceptual change view is taught would not change the situation. It appears science educators need to be made aware of the variety of ways of viewing biology and how particular views are transmitted through lesson presentations and curricular materials.

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APPENDIX A

PILOT STUDY QUESTIONS

Proposed questions for informal discussions with students

The following set of questions is based on the subconcept of photosynthesis which is part of the nutrition section of the Biology 30 curriculum. The questions are meant as examples of the type which will be posed to the students. The subject matter of the questions (i.e., photosynthesis) will be determined by the material that is being taught but the content (i.e., nature of science) will be similar to the examples.

(1) How do you perceive the presentation of photosynthesis? In other words, how do you think of the topic of photosynthesis? Is it a collection of information, an idea, or a theory?

(2) Today in class you learned that photosynthesis occurs in organisms that produce chlorophyll. Where did that information come from?

Is it possible that information is incorrect?

How do scientists judge if it is incorrect?

If it is incorrect, how do they go about changing the information?

How do you judge if scientific information is correct?

Do the labs help you make that decision? If so, how?

(3) When van Helmont performed his experiment on the willow tree, what was he hoping to discover?

What do you think made him do that experiment?

Where did he get his original idea from?

Do you think van Helmont wanted to add more detailed information to science? If so, why?

(4) Today we have more information about photosynthesis than the early scientists did. Are we closer to the truth than van Helmont was?

What is your reason for saying that?

Can you give me examples of things that have happened in your science classes over the years that make you believe that?

Have your science textbooks influenced your idea about scientific truth? If so, how?

(5) In 1801 Englemann performed a series of experiments in which he worked on the two types of pigments that are most effective in absorbing energy in photosynthesis. What do you think was the first thing he did in his series of experiments? How did he go about setting up his experiments?

Do scientific experiments follow a step by step procedure? If yes, why do you say that?

Did Englemann create a theory of chlorophyll a and b or did he discover a theory?

APPENDIX B

OBSERVATION SHEET

Observation Sheet

The classroom/lab

1. Main features:
2. Windows:
3. Blackboards:
4. Tackboards:
5. AV equipment:
6. Special equipment:
7. Shelves and cupboards:

8. Wall charts:

9. Posters:

10. Desks:

11. Clippings:

12. Other:

Teaching strategies

1. Teacher activity:

2. Student activity:

3. Use of the nature of science:

4. Comments on science:

5. Comments on students:

6. Comments on teaching:

7. Comments on society:

8. General comments:

APPENDIX C

SAMPLES OF QUESTIONS SUGGESTED BY THE PHILOSOPHY AND THE SOCIOLOGY OF BIOLOGY

1. What picture of the universe has science given you?
2. Your idea of the solar system appears to be .... where was the earth yesterday? Where will it be tomorrow? How do you know that?
3. Is science coming closer and closer to a better representation of reality?
4. Do biology textbooks misrepresent the history of biology?
5. Is it possible that connections between scientific statements are illogical?
6. Do theories arise from facts?
7. Does biology obey the laws of formal logic?
8. Is biology dogmatic?
9. Is the methodology of biology precise and concerned with exact measurement or is it "sloppy" and irrational?
10. Does biology run according to fixed, universal rules?
11. Is the establishment of objective knowledge the ultimate goal of science?
12. Do scientists abide by the norms of open-mindedness, disinterestedness, impartiality, independence, etc. or do they demonstrate the reverse of these characteristics when they operate in scientific circles?
13. Does biology reflect a definite representation of reality?
14. Does a theory have a different meaning for different groups of scientists? Or, is a theory the same for all scientists?
15. Are there aspects of biological knowledge that are conclusively true (proven)?
16. Is there biological knowledge that is waiting to be discovered or is all knowledge a construction of man?
17. What is the first step a biologist does when he is preparing to study a phenomenon?
18. How do biologists gain knowledge?
19. Do biologists selectively collect data?
20. Why do we study biology?
21. What does biological information allow us to do?

22. If an experiment cannot be repeated so that similar results are obtained can the data from the first experiment be counted as knowledge?

23. After a biologist generates laws, what is produced?

24. Is the scientific method a pre-established set of rules?

25. Is biological knowledge a creation of man?

26. Is biological knowledge culturally influenced?

APPENDIX D

A TRANSCRIPTION OF LESSONS PRESENTED BY TEACHERS "A", "C", AND "D"

A lesson on gas exchange in plants as presented by teacher "A"

A: I'll just review the format so you'll know what to expect. Ah, there'll be thirty multiple choice questions. And about seven short answer questions. By short answer I mean, um, actually I guess in some cases short paragraphs and a couple of sentences. The rest is explanations for things, descriptions of things, and be prepared to describe how something works, what something is like and then ah, descriptions of the, of the, describe either in structural terms or sometimes you have to deal with open structure and function terms. Distinguishing between terms is always an important kind of question. If you are given a pair of words, the way I like to mark that is, you should say something about both. There's one diagram to label. You might be expected to make one on your own. And ah, we touched on, there's one to label. This test ––– open text book statement about cells and how they work as well as reference to lab exercises. We didn't do very many, we did the ––– cells and we did have, ah, a demonstration of osmosis. We saw a film on the cell. Make a reference to that. And we did see a film on osmosis-diffusion. So check all the sources of information, the textbook, films, notes and I think you should do alright. Sort of know what's in there. I would suspect it would take most of the period. Would appreciate it if you'd come with ah, equipment to do the test, that means pen and pencil, you'll have to make a drawing, as well as a far amount of writing. Any questions about it? [5 s p] Very good.

So we'll break from our treatment of autotrophic nutrition then tomorrow and just focus on cells and basic cell processes. Now, on Friday we spent the whole period sort of practicing, or working at this notion of how do you formulate a tentative explanation once you have seen, observed, some aspect of nature. Ah, that got pretty tedious going towards the end. Ah, you seemed pretty enthused toward the beginning and you like to play with ideas and try out your ideas for a half hour or so and then it does get heavy. Now today I'll take another approach and more or less describe to you what I'd like you to work through. That is I will, more or less lecture or dictate and expect you to try and keep up in this way. Ah, we're still on the topic of procurement and we were focusing on how the plant gets carbon dioxide by way of these breathing pores. Just to finish that off. Before, not only the leaves were getting carbon dioxide, they're also used for other purposes. That is, breathing in the case of a plant, like us, is a two way process. It isn't just an intake process, things also leave the leaves by these pores. This structure serves, then we might say, for gas exchange, not just gas acquisition. And if we describe it according to our day and night situation we're over simplifying. We say that during the daytime when there is light the stomates are open, then we have primarily carbon dioxide coming in, and oxygen escaping, as well as water vapour. For these gases to come out and the gas carbon dioxide to go in there must be a diffusion gradient. What do we mean by a diffusion gradient? Or a grade, period? If we're talkin' about highway construction. Have you travelled in B.C.? Have you ever noticed the signs that tell you what the grade is? Particularly in trucking country. You haven't noticed, eh? In some places they post along the highway a sign saying 5% grade, or 6% grade. You haven't seen that? O.K., well if you did see a sign like that, that said 5% grade would you expect they're rating some student? Mike?

Mike: No.

A: No. What are they probably doin'?

Student: No. Grading the earth I guess.

A: What would you interpret it to be if you were driving. Would you expect? What kind of road would you expect?

Mike: Um.

A: Flat?

Mike: Ya.

A: You would. If you saw a sign, grade 6% what would you probably do? O.K. what would you expect?

Student: An angle.

A: Angle. An angle what do you mean? Up like this or down like this?

Student: Down.

A: Down, ya. You'd expect to be going downhill. And the grade percentage would sort of indicate how steep, I suppose. For a very steep grade, truckers need to be warned. It's kind of dangerous. Have you seen those escape routes that go up along side the highway? In case their brakes fail? Alright. Well, we're saying a grade simply means there is a difference between beginning and ending points, I guess. Ah, it's not the same. A diffusion grade in here means ah, what the concentration is like inside is different than what it is outside the leaf. And so there'll be movement from one spot to the other. Things won't be static. Now in terms of oxygen what will be the gradient during the daytime? Anybody want to speculate? [2 s p] Which way would be downhill? Into the leaves or out of the leaves? Mike? Mike? [4 s p]

Mike: Into the leaf.

A: Would the plant be taking in oxygen during the daytime? Ah, that means it would be higher in the air, which is about 21%, than in the leaf?

Mike: It'd be taking it in.

A: Taking it in. Not really sure, here, I guess. Maybe we should put on our general equation again for making food, and then we can speculate, need more background. If this is what's happening during the daytime Bev, which way would the gradient be? Out or in for oxygen?

Bev: Out.

A: Oxygen would be coming into the plant?

Bev: No. It would be out.

A: It'd be out. There'd be a higher level inside the leaves than outside the leaves. That is oxygen would be accumulating in the plant leaves. That is oxygen would be accumulating in the plant leaves so the gradient would be out. So it would be higher in the leaves than outside so it would shift outward. Well, we already have that on the board. Um, you just want to interpret that in terms of the gradient. Higher in the leaves than outside the leaves so it goes out. Concentration of CO_2 on the other hand, if the plant is very busy making food, is the gradient in or out? Lily?

Lily: Out.

A: If the plant is making a lot of food inside the leaf what is happening to the CO_2 in the leaf? Is is being used up or is it being released? Lily? Will it decrease? Is it requiring or giving off CO_2?

Lily: Requiring.

A: It's requiring. So, will the plant be subtracting ah, carbon dioxide from the air or adding it to the air?

Lily: Adding it to the air.

A: Now think just, when you require something and you take it in. Are you adding or subtracting from the environment? Does your food get less on the plate or more on the plate when you eat?

Lily: Less.

A: Less, ya. You sort of use it up. Well, we're saying carbon dioxide here is being subtracted from the environment as the plant makes food. Therefore the gradient is in. From the outside surrounding environment goes in, in the ah leaf, and into the cells of the leaf where there's a package of food. What about water vapour? Water vapour is formed in the leaf from liquid water. The water is coming from the soil, up through the stem into the leaf during the day. And the water evaporates and it makes it through these pores out into the air. I think we should put in our notes , describe this, this transpiration. I'll have quite a bit more to say about that later. When water evaporates from the surface of plants and exits into the air, ah, we call that transpiration. Now I'm just hesitating here because I have a different problem. I don't want you to take ah, plants being simply wet on the outside where the water is sitting like dew drops in the morning on the outside the plant. They evaporate off that outside surface. I really want you to think of water inside the plant, inside the leaves, inside the stems, evaporating inside there to a gas, in, or what's related to gas inside and then the gas is diffusing outward into the drier air. With evaporation of water from the interior of the leaf and then diffusing outward into the air, is really what we wanted to try to say here. Ah, maybe, well, let's see. The evaporation of water on the interior of the leaf, or the plant leaf subsequently diffusing outside. Subsequent means, follow from, take place after. Um, what I've said here is the evaporation of water from the interior of the plant leaf subsequently diffusing to the outside. That isn't the best statement but we'll leave it for now.

Well maybe we can make a sketch to illustrate once more what we're saying. Still working on this concept of day or the time of day, ah make a sketch. What kind of sketch should we make? Suppose this represents a guard cell and we'll put in normal epidermal cell around it, around the outside of it, like so. We're looking at a leaf on the edge.The bulk of the leaf is up here. This is the upper surface. This is the lower surface. We're actually in cross-section. And this represents the stomate. These are the guard cells. O.K. now CO_2 is going in during the day. We have oxygen coming out during the day as well as water vapour. That is as long as that pore is open. How'd you prepare your sketch to represent then the night situation? [13 s p] Would you make one that's similar? This is a little bit tricky. Maybe we would show the pores closed, or at least very, very close together. Maybe the plant is totally sealed. The seal or the hole isn't quite that efficient perhaps. There is still some leakage. In the old days before air conditioning and in the winter time at least when they had to have the windows closed in the hospital, they used to, I recall, remove the flowers and the plant material from the patients room at night and bring them back in during the day. Or at least they'd take them out and put them in the hall. They don't do that any more. The plants sit there day and night. Ah, nobody bothers to move them around. I suppose that has to do with the fact that air in hospitals is circulating. They've air conditioning or at least the air ––– day and night and it doesn't make much difference anymore. Take the old situation, what argument would you use to support the practice of having all the staff move the plants out into the hall at night? [4 s p] Norm?

Norm: The plants surrounding ––– use oxygen.

A: Any idea?

Student: They're taking oxygen away from the patient.

A: They're taking oxygen away from the patient? They're taking carbon dioxide in at night?

Student: No.

A: They're taking oxygen in at night. And who should be having the oxygen at night?

Student: The patient.

A: Patient. During the day time they're probably helping the patient. At night time they're competing with the patient, you're saying. They're using the oxygen the patient might. Which could happen. Well, how is that to be explained? What ––– at this point in our course know about plants and their chemical activities during the day? What do they need primarily?

Student: Oxygen.

A: Oxygen. But as well they're making a lot of what?

Student: Sugar.

A: Sugar. We call photosynthesis, they're making food in the daytime. Now, with the lights shut down, one might think that photosynthesis. Does anything else sort of take on dominance? Does any other chemical process, ah, sort of become the dominant process in place of photosynthesis? Or are plants doing nothing at night? [4 s p] Any suggestions? [5 s p] If photosynthesis shuts down, does everything shut down in the plant? Or are there some other chemical activities that are still taking place? [3 s p] Any ideas? [3 s p] Well, let's go to you. What is the major chemical activity that's taking place in you right now, twenty-four hours a day, that requires oxygen? Do you know any name for it?

Student: Respiration.

A: Respiration. You saw this film on the cell, you saw Lynn Margeless dealing with mitochondria. You should know that mitochondria are involved in burning up food and releasing energy. They call them the powerhouse of the cell. These are, we say, true of not just animal cells but also plant cells. They're found in both kinds. So food utilization, food metabolism, we're saying, releasing energy is also a plant process. We were to put on the board, an equation to represent that it would have the same sort of appearance as the one we already have except for the arrow. Which way would it go? The other way. So the concept I'd like ya to think about here is that there are two sort of opposing processes taking place in a plant. They're not really quite the chemical reverse as we'll learn as we take each one of these in detail. But they're very close. In terms of products and in terms of reactants, they're almost the opposite. Now, during the night time this direction is emphasized. During the daytime this direction is emphasized. I wouldn't want to leave you with the impression that it's either/or, it's more or less. And we're saying during the daytime there is more of this than this. Or we'd say there's more photosynthesis during the day than there is respiration. During night there is more respiration than there is photosynthesis. Then we can almost say there'd be absolutely no photosynthesis but under perhaps a very bright full moon you'd get a little bit. But we're saying certainly at night the emphasis is on respiration, the burning of food. So through the guard cells at night if they are between, if there's a bit of a space, if the stomate is slightly open at least we'd get some O_2 going in and perhaps a little CO_2 coming out. But the emphasis we're trying to make here is oxygen --- during the night. So our arrows then for those two gases would reverse. The water arrow, well it'd become minimal, but I don't think the plant would be taking water out of the air at night, still be losing water to the air at night. That's all I want to say about the gas exchange, ah, the pathways of day and night, of day and night. Do you have any questions about that? [3 s p] Alright, we'll leave that one go and say the leaf is the organ of procurement for carbon dioxide. Now we want to go to another part of the plant and deal with the procurement of water and minerals. What part of the plant am I going to? Mike? [3 s p]

Mike: The roots.

A: The roots, O.K. So we're going to put in our notes next, ah, number two. The topic here will be water and I'll put minerals with it. This drawing is representing the organization of a very young root, a small root tip. This first section here deals with what kinds of specialized tissues that we find in a root tip as it is growing, as it makes new cells. I think some of you went over this in your Biology 10 course and you remember some of the regions. As the root is pushed through the soil they may become damaged. They usually have a package of tissue, right here, on the tip. That could be called a cap. Just behind that, there is a region where they make cells, they call that meristematic tissue or you can call it, ah, embryonic tissue, whatever. What we're saying here is the root cap, you can see that and this is ah, the apical meristem or the tip, or the meristem in the tip for the embryonic tissue is goin' to divide into cells. Now behind that we have the region where the cells get longer, the region of elongation it's called. Finally we get into the section of the root we want to focus on today. We're saying in here cells become rather specialized and we'd call that the region of maturation. Now, if I can hold that on here. (end of tape)

A: ... narrow down to the part of the root we're talking about. And in your notes we can say water and minerals are taken in by the root tips. Primarily by a region called a region of maturation. It is ah, it's in this region that we find a very special layer of cells still in tact. That is the layer of cells we call the outside skin, the outside epidermis represented by this single layer around. This particular layer of cells has walls that are fairly flexible. They can be sort of stretched or be teased apart, that is the cellulose layers in their wall can shift, or slide over each other. If the cell develops quite a bit of turgor pressure, here and there they sort of balloon out. Or we can say they grow these extensions called? Does anybody know? [3 s p] Well, what do you call this that grows out of your skin? [1 s p] Hair. So I guess we can call this hair too. It extends from the skin. Is it the same as yours? Your hair is secreted, it's not cellular, you can cut it off and not feel pain. Um, probably even heat it, stick chemicals on it, you can do all kind of things to it and you really don't suffer very much. Now in this case the hair is really a living structure. It is really part of a cell that extends outward among the soil particles. And to move quickly, that's what I want you to focus on in terms of procurement. The most important part of the ah, root, in terms of getting things from the soil is concerned, is this epidermal layer with its root hairs. Well, let's draw one in our notes. And let's put it in the context of soil. Now, before I begin I want you to get the context. Remember our root is protruding into the soil sort of like this pointer. It's a round, more or less cylindrical structure that's penetrating in amongst the soil particles. We're going to cut this across this way and look at it from the end. That's what you see here. Then we're goin' to show that the hairs come out from the side, like this. Now, I'm going to take just one of those hairs and enlarge it. Let's say this represents, sorta , boxy-like epidermal cell, thick walls. I'll use two lines to show the wall. Then I want to take the site, depending on the chemical balance of the environment and the cell. The wall will be of such material that it can extend under pressure, out in among the soil particles. It won't be nice and straight in the real soil situation. It can twist and bend and curve around particles and find its way through, then, out from the root. If I grew them on filter, that is, if I grew roots on filter paper as we'll probably do this week and then you saw in that context they would become straight. That is sticking out more or less like fingers, ah. These root hairs are extensions of one cell. That is, the whole package is one cell. It has in it a thin layer of cytoplasm and it has quite a large vacuole. The vacuolar sac in this cell is pretty important in terms of what the cell can do. That dotted line is just representing the inner edge of cytoplasm. If I was more careful I'd stipple the whole layer and that has on the outer edge of it what very, very thin structure? [2 s p] Cytoplasm always has on the outside, what? [1 s p] A skin or a membrane. O.K., now it's time to form a note here. That membrane is very much involved in the process of procurement. These cells tend to be alive. So let's put on some labels. Cell wall, that's passive, we can describe it as non-living, secreted but permeable. It has to be permeable if the plants are to get anything from the soil. Immediately underneath that will be the cytoplasm. That will have living properties. It can do work, and the outer skin of that we call the cell membrane. That is not dead and it is not just permeable. Cell membranes are what in terms of what they permit through and what they don't? They are semi-permeable. On the inner edge of that we have another membrane called the tonoplast. That membrane bounds the vacuole of the cell. Now if I tried to show that I'd have the inner edge of the cytoplasm there, we can call tonoplast. That means the membrane around the vacuole, separates the vacuole from the cytoplasm. That is also living and is semi-permeable. If the cytoplasm is very thin we can even consider the whole cytoplasm layer like a membrane. Now the most important liquid in the cell in terms of establishing a relationship outside the cell is the cell sap itself. That is all this material, I should stipple, all this material in here. Primarily water but with dissolved solutes maybe some wastes, some sugars in there. That material we'll label cell sap and it's concentration is extremely important. If the root hair is supposed to take ah, if the root will take something in from the soil this liquid here, in the vacuole, should be what in relation to the liquid outside? [3 s p] What word would you use to describe it if it's going to draw things into itself? [5 s p] Juanita? [3 s p] You have ultimately three words in your vocabulary from chapter six. Hypo, hyper, isotonic.

Juanita: ———.

A: You're Juanita? O.K., what do you think? If this solution is goin' to be effective in, in drawing in things into itself, would it be hypo, hyper or isotonic? [5 s p] You don't know? Bonnie? [8 s p]

Bonnie: ———.

A: Pardon?

Bonnie: ——.

A: Hypo? If this solution was hypo then it would mean that, it would mean that it would have a lot of water and very, very little solute. Water would tend to go which way from it? Out. If you want this solution here to draw something into itself it should be more salty or more sugary or more concentrated solutes than outside of this, and that should, we should describe the word hypertonic. The cell sap should be hypertonic to soil water. It's goin' to draw water into itself. The cell sap is in the structure of the cell called the vacuole. Be sure you put that on, cell sap of the vacuole. Well, I sorta like my own drawing better then the ——. Now if you have room you could put on some soil particles. These root hairs are really quite small. As a particle of soil would be around them, in this position. Coating each particle is a film of water. Maybe even show that somehow as well. Around each particle we have a film of water. That's the water that the roots should be acquiring. Don't want the soil saturated, we don't want it water logged, so to speak. We don't want water dripping out of it sort of like a sponge, out of a saturated sponge because soil must also provide oxygen to these roots, so they can breathe. That is the soil must have some air in it. It should be a bit porous. Um, you've probably noticed around sloughs or lakes when the water has soaked the soil, or saturated it, or the, the lake has risen and, and ah, the shoreline is, is inundated with water ah, the trees, the shrubs and bushes all die. Well, we're saying soil should be able to breathe to occur as well as provide water for roots. And what we're talking about is useful is the water that coats these particles. In your notes at this time then, I hope, the root that is the useful structure for the plant to acquire water, to acquire minerals. The part of the root that is most important is the root that still has its epidermis that still has these tiny hairs. The hairs provide the advantage of, of great surface area. That's why they're important. Just to illustrate that, I'll give you some statistics from a study. I get to the point now first. The point of the hair is to provide surface area, that is, contact with soil. A study was done on a, ah, rye plant. A rye plant is somethin' like wheat or oats or barley, it's ah, it's a plant that used to be very common in Alberta particularly just following World War II. It was a cash crop and the farmers grew a lot of it because they could sell it without worrying about a quota. It was also kinda nice because they would plant it in the late fall and it would germinate and produce a nice ground cover, maybe little green plants about so high. And then it would stay sorta dormant over winter and become active again in the spring and then, ah they would go into the life cycle and produce kernels and they would harvest it. How many eat rye bread by the way? O.K., one person. O.K. the kernel is a little bit smaller than that of wheat. You've seen wheat and ah, less plant on top. It's not a big plant. It extends oh, maybe six feet high. We as kids used to run around in there and have lots of fun, much to the farmer's, a sorta, you know frustration. Um, it grew quite tall, six feet. It's kind of fun to run in there and hide on each other. Anyway, back on track. We're saying this plant being four months old estimated on the average to have fourteen billion living root hairs. Now fourteen billion should indicate to you that they would provide a lot of surface area. The point of having so many is to make sure the roots are contacting a lot of soil. If you took each little root hair and split it and unfolded it like a piece of paper instead of having it in a tubular pattern. You open it up like this and laid them side by side, this person doing the study, ah, suggested it would cover about 4000 sq ft. I suppose he had a system, ah. Pretty big surface area, 4000 sq ft, for this one plant to contact the soil. Now these root hairs, they look like a dig, so they would be damaged, die. After about a 24 hour period and you have a new batch being produced. The concept we'd like here is that ah, there is continually turning over. Old ones are being replaced by new ones, sorta on a daily basis. I'll repeat the main point. The function of root hairs is to provide surface area for absorption. Their function is not to anchor the plant, that is to make it stable in the soil, their function is to procure things from the soil. Well, back to the process now. If the roots are procuring water, the solution around the particles should be hypotonic to the solution inside the hair. I'm not contradicting what I said before. Before we said it the other way around. We said the solution inside should be hypertonic to the solution outside. If you have room yet you can put that on your drawing. I suppose we're saying this solution we already have, the root hair one, this solution out here, the soil water should be hypotonic to the solution inside. Well after a nice spring and early summer rain that's how it probably is. During the hot dry days of August, it might be the other way around, the soil may be hypertonic and as a result the plants then to do what? [2 s p] Dry out, wilt, ah, droop and then along comes a nice rain again and they then sort of stiffen up and become turgid. We say, ah you can see sort of what condition the soil is in by looking at the plant. In the city situation you'd probably get out there with the hose and water. Or if you have your lawn automatically watered you just turn on the tap and out comes the water automatically and your plants become nice and turgid. Well, the ah, if you're in an apartment of course you take your plants and water, right? We're saying let the water go through the soil determines which way the water's going to go in terms of the plant, in or out. The soil water should be hypotonic to the cell sap. Now, in your notes maybe we should summarize the ah, the method then the plant uses to obtain water. Number one process, I've been indicating here to obtain water is ah, what? [1 s p] We've talked about the hypo, hyper water going in by diffusion. What is the process we're dealing with? [2 s p]

Student: Osmosis.

A: Osmosis, sure, It's on the test tomorrow. We know all about that. By tomorrow anyway.

That's the main way the plants acquire water. Ah, research has shown however even when the soil is pretty dry and you'd say it is a hypertonic position. Ah, that means the water, out here, is not in as a great a concentration as the water in here, or the solutes out here are more, more abundant than they are in here. If the soil water is hypertonic, water is sucked, for some reason, still goes in, it's still picked up. A minor method, but still important, is where the membrane gets involved and moves water against a diffusion gradient. When you're describing a movement like that for minerals like iodine in algae, or sodium in nerve cells we call that what?

Student: Active transport.

A: Active transport, sure. We'll put that down as a second method. Put a mark beside osmosis. We'd say that's the most important one. But active transport does occur for water. That's all I want to say about water procurement. Now, a bit about minerals yet. Ah, what kinds of minerals do plants require to make their food? If you look at the make up of sugar you might come to the conclusion they don't require any. Well, let's see if can catch up on how our notes are organized. What you have here is the procurement of water and minerals. You've made some notes about root hairs and root structure I hope and ah, what I've just listed on the board is applicable to water procurement. Now underneath that same heading we'll deal with minerals. Root hairs again are involved. It requires the root hairs. Before I get into details of ah, of what is acquired, what minerals are taken in, just put the points of main method is active transport, is well documented by studies carried out here in Alberta, and I might refer to them after a bit. Now the types that are taken in, well you can get a clue by reading your fertilizer bag. Now, what kinds of minerals do plants need? What would you put down as the number one of, the number one was primary importance. Any idea? What's the chief ingredient of fertilizer? [2 s p] What's number one on your bag, the very first number on the bag is the amount of what? [1 s p]

Student: Nitrogen

A: Nitrogen, sure. Well that's of primary importance. Well, if I take the photosynthesis, and that is the context of our lesson today, ah, if I do our little equation once more, here are the reactants, do you see any nitrogen in there?

[1 s p] Here is the product, he said, sugar. Do you see any nitrogen in there? It doesn't become apparent by how we describe photosynthesis that the plant will even need this mineral. Which we buy at quite a great expense, because we're dealing with it on a farm scale, and add it to the soil. So you might want to put down why this is needed. It is not needed to make sugar directly. Can you suggest some indirect necessity for it? [1 s p] Any idea where it might be needed in the process? [6 s p] It doesn't become apparent from what we've studied so far. So I'll probably have to help you. Nitrogen becomes very important in the making of some of the chemicals used in the making of food say in the machine, or factory of photosynthesis. And, ah, nitrogen is important in making the plant green. It is important in the synthesis of chlorophyll. Not because it is in the chlorophyll molecule itself but it is used in helping the chlorophyll to be made. Maybe you've noticed if the nitrogen is scarce in the soil the plants do not have that deep bluish-green tinge. And you can easily tell where you've put the fertilizer and where you haven't if you've done any fertilizing of your lawn. You sort of tell after two or three weeks where you might have missed. When you drive through a community you see lawns repeatedly, you probably don't look at them, you probably look at the other things, like people grass. But in the case if you look at lawns, you might have noticed sometimes, the lawn looks a little patchy, depending on how the person did that, applied it. You can sorta see dark green patches interspersed with light green patches, as if they went out there with their hand and did it this way. Or if the spreader sort of stopped and got plugged up and then cleaned it out and starts again you forgot where you left off you get sort of an uneven patch, ah pattern. Well you all know some chemicals in cells that have nitrogen in them directly, ah, one in particular. Can you name ...? Ammonia has nitrogen in it and plants need this. Amines have nitrogen in it and amines are used for making what big complicated molecule?

Students: Proteins.

A: Proteins. What we're saying is if a plant is goin' to have enzymes and the machinery of membranes, that it's going to have to have nitrogen. So, to summarize what we're saying, nitrogen is absolutely essential to build the enzymes that participate in photosynthesis. Well, what other ah, mineral do you see on your fertilizer bags? The second number, do you know what that stands for? [3 s p] Let's say we have a fertilizer bag with the formula 6-12-0, something like that. You always have three numbers on the bag. Ah, these are percent figures. The first one means the percentage of nitrogen by dry weight, that's the percentage of the total. Let me repeat that. We're saying the first number represents the percentage of total dry weight of ah, contents of the bag, ah that, that is nitrogen there. What's the second number represent? [3 s p] Well, let's give you a clue. That is beyond what you normally think about I'm sure. The second number is ah, representative of phosphorous. Now, phosporous isn't required in as very large quantities as nitrogen. You can put some number on these things and say nitrogen is required let's say 15 --- in comparison to that, phosphorous is required in two parts. The third number on the bag is, we're simply going in alphabetical order here, the third number is potassium. This is required in larger amounts than phosphorous. The rating here is about 5 parts. O.K. then the three most important elements that we, here in Alberta, think we should be adding to soil, depending on our soil condition, and you vary the formula from spring to summer, to fall. What you put on in the spring emphasizes the minerals that help the roots to grow and later on you emphasize the nitrogen a bit more. This number becomes large on the bag and these get smaller. O.K., ah, just want to add a few more that plants require. In the same league, Alberta soil usually has lots of calcium, calcium, sulphur, and magnesium. These six we'd say make up what we call the macronutrients, the big items. The major minerals required by the plant to grow. I'm saying the fertilizer bag, or the little bottles you buy, for your houseplants are probably emphasizing these three. These three are usually adequate in the soil. I do want to single out this one and just comment. Magnesium is required for making chlorophyll. It is in the very heart of the chlorophyll molecule. Without magnesium the plant cannot possibly be green. Magnesium to a green plant is like iron to red blood.

A lesson in gas exchange in plants presented by teacher "C"

C: Now chapter twelve dealt with a little bit about gas exchange in plants. And first of all name, naming the two gases involved Heidi. In transporting or exchanging gases in plants are going to be?

Heidi: Carbon dioxide and oxygen.

C: Carbon dioxide and oxygen. These are also the two gases that are involved in animals. As a matter of fact those are the two major gases that are involved in all life. Now there could be certain organisms, for example bacteria and maybe the odd virus or so that's not necessarily going to need any oxygen what so ever. Now this exchange of oxygen and carbon dioxide will take place with its environment. One of the necessary components for oxygen to exchange places with its environment from with inside the cell. What is one of the major factors or components necessary for this operation to take place. The movement of oxygen from its environment with inside the cell. There is one component that is necessary. Mary?

Mary: Water.

C: Water. O.K., now that's going on the premise that one of the statements that I made is that... The way we define life, one of the necessary components, and obviously there's going to be some organisms that will dispute that but by a large extent there... But most organisms that are considered to be alive, or cells that are considered to be alive are going to be surrounded by a fluid. And that fluid is going to be the extracellular fluid. Back in chapter six we took up some of the things that must be kept at a constant level in that extracellular fluid. And we termed and phrased that constant level of, of oxygen, carbon dioxide, pH... What term did we apply to that Glen? To things that are kept at a constant level? [3 s p] And it's not equilibrium. It might be isotonic? Well that's comparing food materials on opposite sides of a membrane, then they are equal, isotonic. But if things are kept constant (4 s p) Janet?

Janet: Static.

C: Static almost. There is a word that is applied to that. Static is fairly close. What would go along with that. Lynda? [2 s p] Joyce?

Joyce: Homeostatic.

C: Homeostatic. So that now something is homeostasis. That means it is going to try and control a certain level of materials in its environment. And these materials in the environment must be kept at a fairly constant level. One of those things or I should say two of those things that must be kept constant in the environment of a cell are going to be the gases involved. Those two gases that Heidi stated earlier are going to be carbon dioxide and oxygen. Most organisms are going to consume the carbon dioxide in their chemical reactions. And if they're consuming carbon dioxide they're probably using other materials for example, water and they'll be releasing oxygen. Or they could be for example taking in oxygen and releasing carbon dioxide. Now those are the two major processes of like. The building of the complex material which is the consumption of the carbon dioxide or making of sugar. Or the breaking down of the sugar molecule and the releasing of carbon dioxide as a by-product. So those are the two major gases involved. The two major processes using those gases are photosynthesis and cellular respiration. So if those are the two gases then somehow we're going to deal with plants first. Somehow those plants have to acquire the gases that are necessary. And in plants one of the major gases necessary is going to be carbon dioxide if we're talking about the leaves. But carbon dioxide is needed for the process of photosynthesis. Now you know yesterday we talked a little bit about roots. And a few of you weren't here yesterday. Ron seeing that you weren't one of those people, what is one of the necessary components that will be absent for roots that will be present for leaves? (3 s p) Now think, it's going to be around for leaves but not going to be around for roots. I'm going to ask the people that weren't here. Barrie?

Barrie: Oxygen.

C: Oxygen. No. Something else.

Barrie: Sunlight.

C: Definitely. In most cases roots are going to be down under ground. Most cases leaves are going to be found above ground where there is sunlight. Now going to that concept of structure and function, we have two materials that are going to be described differently. We're going to have the leaves that are going to be described differently. We're going to have the leaves that are above the ground are going to be described different than the roots that are below the ground. Now we, because of that structure we're going to deal the gases different. If the structure is different chances are the function is going to be different. The leaves that are above the ground require the sunlight and the carbon dioxide mainly. Yes all the cells require oxygen but we'll get into that later. Underneath the ground there is no sunlight. The structure is different, the two gases involved are still carbon dioxide and oxygen but they use oxygen because the function of photosynthesis requires carbon dioxide and there is no photosynthesis in the roots. So in the roots they're going to be taking in oxygen and giving off carbon dioxide. And in the leaves they're going to be taking in carbon dioxide and giving off oxygen. So their structure is going to look for different functions. And those functions are going to be the use of gases in different ways. The same gases but using them in different ways. The same gases but using them differently. Now, I went through yesterday , I went through how gases get into the roots and stems. To a large extent if the oxygen is going to make it into the cell it must be dissolved in somehow in the water. The soil is going to have moisture films around each particle and the roots coming into contact with the water and thus take in the oxygen. Because they don't photosynthesize they need oxygen. Carbon dioxide will be eliminated in the opposite direction. So the roots are going to need Barrie, air spaces which contain oxygen. O.K., now the leaves on the other hand...

Lawson: How come they have to get oxygen? How come in some plants they're supposed to sit in the water? Like when you just cut off a shoot and place it in water?

C: O.K., alright. Good question. If he's just taken a plant, and he's talking about making a slip or something. Usually when you make a slip where would it be? Tell me how you go about making a slip. The process, that's not with a sewing machine, a slip from a plant.

Lawson: ——.

C: What would you do? You just basically told me.

Lawson: Snip off the plant.

C: And then?

Lawson: ——.

C: O.K. Where are the roots of the plant?

Lawson: Still attached to the plant.

C: Still attached to the plant under the ground right?

Lawson: Ya. ——.

C: Right. Right. That's right. What you've done now by taking and placing the little slip in the water is bring the water in direct contact with the cell. Eliminating the roots.

Lawson: ——.

C: They don't necessarily need a large quantity of oxygen, because we don't have the roots. And any oxygen that's dissolved in the water, should be enough oxygen to look after the oxygen requirements of the cell. O.K. so by cutting that piece of twig off and putting it in the water you've eliminated the roots so you don't need the function of those roots anymore.

Lawson: Then why do you think there are roots?

C: Ah, well that's called differentiation. That's specialization and that's controlled by hormones. We'll be getting into that a little bit later. Maybe we could keep on going with this but it gets off track a little bit. So we if we keep with the gas exchange. That was a good question about the gas exchange but the extension of the roots that gets us into hormone control. And let's get the gas exchange first and the we look up how

Lawson: I just thought that if they had enough oxygen to make roots

C: Well you see, --- a viable plant you have have to have an organ system. An organ working with another organ with another organ. So you have roots that are no longer there. You have snipped them off, so you have a stem which could be an organ. The leaves which could be an organ. So as an organism it's incomplete. Alright? And for it to have any form of growth it would then have to take in more water. The best water absorbing type structures are roots. So therefore as a function it would like therefore at least to develop a structure that's going to look after it. I'll keep working structure and function at you guys until you understand it. Everything has a function because it has a structure, and that structure is going to have a direct bearing on how that function is carried out. O.K.?

Now what we're talking about leaves we have a process of photosynthesis which is taking in of carbon dioxide and the union of water. I'm over simplifying this process, energy of the sun... Sure over simplified but none the less that's basically what happens. When we're talking about the exchange of gases within a leaf, the leaf is usually outside. We'll talk about terrestrial plants first and we leave the aquatic ones alone. The terrestrial plants usually have an atmosphere that contains both gases oxygen and carbon dioxide. I'm going to concentrate on the carbon dioxide intake of a plant and I'm going to show you how it gets into the leaf and also how the control of gas exchange is controlled by the guard cells.

Now, the cross-section of the leaf. At the top of the leaf you have a water resistant cuticle, a layer of epidermal cells which is something like your skin, they're transparent, protective. There's a layer of cells just below that which are the palisade mesophyll, the palisade layer they contain a large number of chloroplasts and that's where the process of photosynthesis will take place. We have another layer of cells, these are spaced out all over the place. Large spaces in between. They are spongy mesophyll. There's a lower epidermal layer, a lower cuticle and also an opening or a pore. This pore is the stomata. The stomata is controlled by two distinct cells that are kidney-shaped on either side of the opening. They're either going to be open or closed. Now if it's open obviously there's going to be great oxygen loss and carbon dioxide intake, water loss. O.K.? Obviously. If the pores are open, it's like you when you sweat. If your pores are open you sweat. When your pores are closed obviously you're not sweating. [4 s p] It's not exactly the same but at least you get the idea. When the pores are open there's going to be a great loss of material as well as an influx of materials. So the opening and the closing are controlled by the guard cells. When the carbon dioxide comes in through the stomata it comes in contact with a film of moisture that is surrounding all this spongy cells. It then becomes dissolved and can be transported to all parts of the plant which require carbon dioxide for the process of photosynthesis. Alright, now if I want to look at carbon dioxide intake I have to start to look at what is going to control the opening and closing of that stomata. Which are the guard cells. Now if I draw guard cells greatly enlarged and I'm going to look at the guard cells and most of the guard cells are located on the underside of the leaf. So I'm going to give you a picture on the board of looking at the underside of the leaf. Guard cells here, stomata is here in the opening. The structure is that, such that the inner layers of the guard cells are much thicker than the outer layers. O.K., now I can't just all of a sudden isolate the guard cells because notice there are other epidermal cells on either side so... I don't know what kind of a plant would have cells like that anyway. You have cells, epidermal cells, the opening and closing of that stomata, that might be the opening here, is controlled by these two large kidney-shaped cells. We also in the previous chapter where we have osmosis taking place. And osmosis is established when you have for example, concentration gradients set up. So you have a solution which has a high water concentration separated by a membrane and a water concentration which is low. We're going to have the water move from a high water concentration to a low water concentration. Now if we have a container that has water on both sides of a membrane, if it was pure water, water would flow in both directions equally. And Glen there is your isotonic. Now if for example I took, oh some sugar, some glucose, and I sprinkled some glucose in this side... Try and keep the volumes about the same, I'm not concerned about the volumes, concentration. If this is pure water in relationship to this, this is going to have a high water concentration compared to this water concentration which is going to be low. So by increasing the solute on the right hand side I decrease the water. Therefore the movement of the water is going to be from the left hand side to the right hand side. O.K., I'm going to try and do that here. Contained inside these guard cells are structures known as chloroplasts. Now the water concentration to begin with is the same thing. The water concentration around the epidermal cells are exactly the same at the beginning point. Now early in the morning when the sun comes up and it strikes the leaves, the leaf will begin to photosynthesize. The end product of photosynthesis will be? I should be working in this direction. The end product of photosynthesis is going to be glucose. So early in the morning when the sun strikes the leaf it causes these chloroplasts to photosynthesize and produce glucose. The epidermal cells do not contain chloroplasts they're only clear. Therefore, they're not increasing the solute. So now what we have is the water concentration inside the guard cells is going to what? [4 s p] In relation to the water concentration in the epidermal cells. Julie what's going to happen? You've got a high water concentration on one side of the membrane and a low water concentration on the other side. What's going to happen?

Julie: Well, ---.

C: Sure. Excellent. Sure that's all there is to it. So, some of the water from the high water concentration is going to move inside the cell. Lois, what's going to happen to that guard cell?

Lois: Expand.

C: It's going to expand. It's going to swell. Now, rather than trying to erase and try to draw all that thing again I'll just re-draw this particular cell. Now, you'll notice it's quite a bit larger. So it's taken in a lot of water. Now if this guard cell is taking in water this guard cell probably is also going to take in water as well because it contains chloroplasts. So you end up with a situation where the guard cells become greatly enlarged because inside the water concentration is low and as glucose (end of tape)

...you have the stomata open so that carbon dioxide can move in. Now did you get all of that yesterday? Did you get any of it? Some of it? O.K., stomata controlled by guard cells. The walls are thick, elastic, the outer walls are thinner. When turgor develops the thin walls bulge out forcing the inner walls into a crescent shape which is going to open. The loss of turgor the guard cells are closed. Now the process I've just described to you and also written down. Now we can apply the effect of pH on the stomata as well. And we will do that.

O.K., if you can just bear with me. I want you to drop your pens. Put them down. I want to finish off this part plus the part that's coming up. Now I've described what is coming up, basically to you already. Now I'm just going to apply it with just a little different concept in mind. Concerning about plants. O.K., again light stimulates the opening of the stomata by first of all stimulating photosynthesis in the leaf, number one. Number two, which causes a reduction in the carbon dioxide concentration of the air in the air spaces. This is the reduction of carbon dioxide O.K.? Now, which increases the pH of the cytoplasm of the guard cells. Now why would the pH increase? Anybody have an idea? Increase means becoming?

Student: Basic.

C: Basic, therefore carbon dioxide is probably going to be found in what form, with water? Producing carbonic acid. So now if carbon dioxide ---. As soon as the sun comes up in the morning and photosynthesis starts which is the consumption of carbon dioxide is reducing its acidity or becoming more basic. And as it becomes more basic the pH increases. Everybody with me so far? Which promotes the accumulation of solutes. Glucose. Actually phosphoglyceraldehyde or PGAL. Which causes the water to enter the guard cell by osmosis form the surrounding epidermal cells which we've just looked at. Which causes the build up of turgor and the stomata open. (13 s p) Now most of you are probably there. Do you need it any higher? Now, outside carbon dioxide is found --- carbonic acid. Now, know that it's not going to be found as carbonic acid because that is a very... It could be very bad for a plant to have large quantities of acid floating all over the place. Yesterday when I went through it I described to you that the carbon dioxide when it joins with water produces carbonic acid which then dissociates into a bicarbonate allowing hydrogens to be released. And anything that liberates hydrogens is classified as an acid. But to understand how it is with plants you have to understand a little bit about the union of water with carbon dioxide. It stimulates photosynthesis and causes a reduction in carbon dioxide concentration in the air in the air spaces which increases the pH of the cytoplasm of the guard cells which promotes the accumulation of solutes which causes water to enter the guard cells by osmosis, which causes a build up of turgor. The guard cells swell.

Student: ---?

C: How long would it take for a guard cell to open? Not very long. ---. But it would depend on three or four things. The accumulation of glucose, how fast ---. It leads to some very interesting kinds of questions. O.K. question. How could I artificially, after I've stated the process of photosynthesis open the guard cells. How could I very quickly close the guard cells? Glen?

Glen: ——.

C: So if I added carbonic acid it would lower the pH and it should drop and guard cells would close. Take light away.

Student: Is light more important?

C: Ah, good question. Is light more important? You answer it for me.

Student: ——.

C: O.K., now we will find out later on why why it is more important. How else could I stop this from happening? Blake?

Blake: ——.

C: If I have the guard cells open, how could I stop the guard cells from opening? Or how could I close the cells artificially besides turning off the light? Introduce acid. How else? I'm saying artificial so you can come up with anything. Conjure up any idea you want.

Blake: ——.

C: Alright. Take a needle, stick it in and bring out the water. That would reduce what?

Student: ——.

C: It would reduce pressure. What is that pressure called? Say it. Say it louder. So if I could reduce the turgid pressure within the guard cells then the guard cells are going to close. I could do that also by reducing the temperature because it's going to be a chemical reaction which photosynthesis is. So if I slow the rate photosynthesis down by reducing its temperature I should be able to prevent an accumulation of solutes. I could also stick a needle inside the guard cells and even extract only the glucose, therefore the water as Glen said earlier would be in an isotonic situation and there'd be movement of water equal and the pressure would be reduced. What's that?

Student: ——.

C: If you added sugar to the epidermal layer and you've created an isotonic situation again.

The next little bit is just a bunch of facts that can be applied to gas exchange and that is kind of fill in some empty parts along the way. So the actual gas exchange parts of the plant are going to be the primary the oasis areas which are bounding spongy mesophyll. And again that relates back to the fact that I keep harping at you is that a cell that is usually considered alive is going to be surrounded by a fluid. Of course there are situations where you have a spore formation and stuff like that. But then again they're a special kind of life. Almost like suspended animation. So we won't concern ourselves with those right now. But an operating cell needs to be surrounded by fluid. And this fluid which is surrounding the spongy layer, O.K., now you can begin to draw correlations between plants and animals. Gas exchange in plants they must have oasis cells. The two gases involved in plants are carbon dioxide and oxygen. Your start looking in animals, the two gases involved in animals are going to be oxygen in, carbon dioxide out. The same two gases. Chances are because we're working with the same two gases the structures involved are going to be quite similar, and they are. Inside the stomata, or inside the leaf they must have spongy cells surrounded by water. Inside the lungs when we're dealing with oxygen and carbon dioxide the alveoli, which are the tiny little structures, have to be coated for. There has to be a fluid made available. And this is very evident when you get yourself a cold. Your whole bronchial system begins to dry out and you begin to notice it becomes very difficult to breathe. You can still do it because you don't dry your lungs out completely. O.K., so there you go. Two gases, the functions are very similar; therefore, you expect the structures that have some similarities. So water loss is prevented by the epidermal cells covered with a protective covering, a waxy covering called cutin or cuticle. The water vapour that passes out of the leaf through the stomata is called transpiration. And we're going to be doing more of that later and in chapter fourteen. But anyways there it is. When water leaves a leaf it is called transpiration. Transpired water is transported by water from the soil. And that's why you throw water on the soil to water your plants at home, rather than on the leaves. Water is taken up by the roots, to the stems, to the leaves. Now an extension of that, getting into a little bit of transport but it does fit in a little bit. The transpiration drives the transport mechanism by which inorganic nutrients are brought in from the soil to the leaves. So if the leaf, in its process of manufacturing certain materials they need some inorganic materials, those inorganic materials come from the soil. How do they get to the leaves? They get there by the transport of water. The vessels named are the xylem. Transpiration is a cooling process. Each stomata acts like a humidity sensor. Again I go into more detail in chapter fourteen, go into it, how it acts as a humidity sensor. If water is acting as a cooling process does anybody have an idea how it happens? Or why? Anybody want to try it out? How can water act as a cooling process? Evaporation, O.K.? Now how does evaporation cool? O.K. evaporation is correct.

Lawson: Doesn't it ---?

C: O.K. now most of you realize when you sweat you release fluid. Fluid is now coating your skin. What happens is, the moisture that is now on the outside of your skin absorbs the heat from your body and in the process of absorbing heat the moisture on your skin evaporates. So it has taken heat energy from your body to evaporate the water. The same basic process is taking place in plants. The water that is being transpired coats the outside and inside of leaves. As the sun is beating down on tops of the leaves it warms the leaves up. Some of this heat is transferred to the water. The water then evaporates. In other words as the water is evaporating it is taking heat away from the leaves; therefore cooling the leaves. There is a process that is called photorespiration. One it might be a little bit difficult to understand at this point because you haven't really taken photosynthesis; you haven't taken respiration. Now when photosynthesis begins it is an accumulation of glucose, glucose is an increase in solute; therefore, there is a concentration difference and water moves into the stomata and the stomata open. Well, if the stomata also contains other materials that taken the glucose and break them down. The broken down glucose then add to the carbon dioxide concentration. Now the process of breaking glucose down is called respiration. Respiration is greatly affected or more so affected by temperature increase than photosynthesis. So, the sun comes up in the morning it hits the plant, the stomata open because there is a build up of glucose in the guard cells. The guard cells because they're being warmed up also have their rate of cellular respiration increased. Now cell respiration is taking glucose and breaking it down into carbon dioxide and water. As the sun keeps beating down on top of the plant, respiration is suddenly going on faster than photosynthesis. Well we have a reverse situation. There is less solute; therefore, the stomata close shut. And that usually takes place in the hottest part of the day. So basically during the hottest part of the day respiration is going on faster than photosynthesis. And that's called photorespiration. Also its kind of funny because that's when most people water their lawns. And that's probably the worst time to water your lawns because the plants take in water corresponding to the water they lose during transpiration. Well if the stomata are closed their not transpiring; therefore, they're not taking anything in. So if you're watering it soaks down into the soil and the grass doesn't even use it. so if you want to water your lawn you water it early in the morning when the sun first comes out, the stomata open, there is a lot of water loss; therefore there's going to be a lot of water intake.

Student: ---

C: Not in the hottest part of the day. Well, the hottest part of the day if you keep watering it long enough you can cool the grass down where it will work but you have to use quite a bit of water. So photorespiration, or respiration of photosynthesis are directly related to the temperature; therefore, as the temperature increases so does respiration at a rate faster than photosynthesis. So the stomata close. The concentration of carbon dioxide rises. Or in other words the solute concentration decreases; therefore as Glen said, the situation would be what, Glen? The same concentration. Isotonic.

Now there are a few plants that prevent this from happening. So that if a plant can keep its stomata open all the time that means it is constantly taking in carbon dioxide; therefore, it can constantly carry on photosynthesis and it's probably going to produce more food and more food it produces obviously the larger it's going to grow. Some of these plants for example like corn, sugar cane. Most of you realize corn can grow two or three metres high in one season. In one growing season. That's why if you've ever noticed crab grass or quack grass, why after you've finished cutting the grass, three days later the quack grass needs cutting but the other lawn is still small. Quack grass prevents photorespiration from happening; therefore, it's going to photosynthesize faster and produce more food. so theoretically if geneticists can develop plants that resist photorespiration our food production can be greatly increased. O.K. we're almost done. The last part tomorrow's class. Make sure tomorrow's class you bring your labs. ---- handing it back to you. We're going to be using that as the basis for photosynthesis lab. You're going to have two unknowns. Two unknowns, what's tomorrow? Wednesday. Thursday you get a test.

An introductory lesson in autotrophic nutrition
presented by teacher "D"

D: ... along the lines of what Mr. Benson has to say. I'm not so sure that, that one should read the text and just get really confused and then we go through it in class and the way I present it, it is a little bit different ––– the main confusion. ––– I'd just as soon confuse you myself as have –––. There are some facts here that when we get into some biochemistry that will prove to be a little more difficult for some than –––. I'll present it in a much different fashion that the text because I think I have an easier way to do it. So what I suggest to you then, if you're going to read the text through, just read the first part to give you some of the facts. Once you get into the reactions which is nine point six, the dark reaction –––, nine point six and on from there you might not read that so much. Listen more carefully as to what we do in class. I've scheduled a long period of time to go over this unit because it takes a little bit of time for it to sink in. And often we go through it in basics we have to go over it in general and then try to work our way down to give us an understanding of concept and then we'll get down to some specific information. And then we may try to look at that from three or four different viewpoints and what we want to do is –––. I found at the end of last semester when we went through a review of this unit it took about ten minutes to review it and then ––– understand. They recognize that, that ten minute review was worthwhile because we spent four weeks, or how many periods in this case, during the course going through it in a very slow and careful fashion. Now in introducing this, ah, I'm not going to call this photosynthesis. We have another title for this unit which I think much more indicates what we are discussing. And that is energy transformation. So far we've discussed the cell, what it's made of, atoms and molecules. We've done a lot of chemistry and we have some understanding to the processes. Last unit we discussed previous to the cancer was this idea there are some transformations that involved in metabolism. Why is a cell living Lorna?

Lorna: –––

D: It was sort of that question on the test. ––– equilibrium. Notice this desk is all combined together. Sam?

Sam: Is it the transfer and exchange of energy within the cell?

D: O.K. Basically that's what you're trying to say I don't want to –––. Basically what we said or tried to conclude this by using a big work so it sounds more impressive, cells are alive because of their ability to metabolize. Which meant exchange things with their environment and make transformations inside. And that is the quote, condition for life. The ability to metabolize. Now the key concept to being able to metabolize is the energy for chemical reactions. We talked about enzymes and how they do their job and electrons and stuff. What we want to do now is step outside the cell itself and look at energy in general and this first introduction is a lot of theory.

But if you'll pardon my using some terms that as I mentioned. A theory based on what we consider to be some laws. Which you were supposed to learn in chemistry. Alright, the first concept. I'm going to go through five concepts during this period, so by the end of the period there should be five things that you learn. O.K.? I'm not going to number these one, two, three, four, five. We'll just go through them.

The first concept is a mathematical formula. Alright, what does that mean Dave?

Dave: Um, the universe is made up of things that, I don't know, things that are alive?

D: Dana.

Dana: It's made up of everything.

D: Pardon me?

Dana: It's made up of everything.

D: The universe is made up of everything? Lane?

Lane: Ah, it's made up of living systems plus the surroundings around it.

D: I did put down originally, it has to be be in a living system. You might as well jot down we'll be talking about ... So what was that again Lane?

Lane: The universe is made up of living systems plus the surroundings.

D: O.K. Now let's come back to the shelf again. Dana, what was the universe again?

Dana: It's everything.

D: What's your concept of the universe, Dana?

Dana: It's everything.

D: Sort of everything that makes up everything. Is that what you were going to say?

Dana: I don't know.

D: Camile, where are you? What's the universe?

Camile: ——

D: Everything that's in existence right? Sam?

Sam: Um, —— system in balance?

D: O.K. What you're talking about now you get into another concept. Everything, this everything is in balance as well. Is that what you're saying? O.K. let's try and focus on the earth then. That's what we really like to focus in on then. Dale? What's in the universe?

Dale: Space and all the things in it.

D: Space and everything inside. That's nice. That's spaceship down or something? Space like this? Do you mean outer space? Or inner space? Is there anything is space?

Dale: I said space and the ——

D: Is there anything in space which is what you said. That's what I'm asking. Space is everything that is in that space. Is there anything in space?

Student: You're switching. In a space, a space. There's nothing in a space. What he said was space. And there's nothing in front of it.

D: The space. Dale, I'm not trying to make fun of you at all, it's something I've thought about a lot too. When is the universe? We use a symbol often to represent the universe? What's the symbol? Naja? Infinity, right? We use the symbol, don't necessarily write it down, but we use that symbol to represent the universe. As you all said, Dale said it best of all, as you've all said the universe has everything in it. It's very difficult to give just a finite position or statement on the universe because the universe is not finite. Alright, it's infinite. And so when ... I was, sort of playing on Dale's concept, Dale's concept is the same as ours. When you think of the universe ... You remember going through it as a little kid when you first learned your address. 115 or whatever, then Edmonton, Alberta, then Canada, North America, earth solar system, and the universe is at the end, whatever that is. —— elementary schools when you tell everything about everything. Ah, we use this term universe to talk about everything, get none of us really understand it, what the universe is. It's a concept that, that's beyond our understanding, because you and I understand things that are like you and I have barriers. It's got to fit inside barriers. You must don't understand it. It doesn't make sense. We're talking about living systems that are found in this infinity, alright. And we're going to be discussing some energy transformations as they relate to these living systems and so we need to bring down some boundaries if we can understand our living systems and the energy that's required to make this system work. So we use a little formula that stands for the universe, that's everything, whatever everything is. And that's why, when you said is, when I said is there anything in space, it's not quite as ridiculous question as it seems. What is there out in outer space where there's supposedly a vacuum? Is there something in there that's not considered to be space? That's invisibly small, that's in another dimension? We start to get into philosophy. We don't know. We just don't know. We do know something about living systems and they're fairly concrete. And so to make the formula work we say that the living system, which you and I have an idea of, we would use ... We will talk about the sun to start with. That living system is definitely a part of the universe and everything that's outside of that, everything, plus this system is going to make up the universe. O.K. that's first of all, then give us some boundaries definitions. The universe includes everything, this includes all the matter, includes all the energy because the universe is everything. That can be broken down into a finite system which is made up of some of that matter which is going to use some of that energy plus everything that's going to be outside that system, that surrounds that environment. Outer space, everything, that's outside that. Make sense, Dale? It seems probably pretty trivial when you look at it right off the bat. Alright,

Student: ---

D: O.K. you're adding one more concept to this and that is ah, something to do with energy. If you want to just hold onto that for just a sec. Let's just talk about the matter portion. Matter can neither be created nor destroyed. What does that mean? Gerry?

Gerry: Well ah, there's ah a finite [amount

D: [There's a finite amount of matter.

Gerry: And it can only be transformed ---.

D: O.K. it means there is x amount of matter. Is that what you're saying?

Gerry: Yes.

D: And you can neither create it nor destroy it. You can make it a different shape or kind but you can't destroy it. There's a finite amount. Is that what you think, Laverne? Is that what your concept of this law?

Laverne: Ya, that's

D: Which, more or less?

Laverne: Well you can't just make more?

D: You can't must make something from nothing I think we all have that concept, right? Atoms have got to be there. You can rearrange them in a chemical reaction, you can change the partners. You can't just make it out of nothing. Right? And so we say there has to be a finite amount of matter right? What about your unit on nuclear energy? What about that unit?

Student: We took food and

D: You took foods and ——.. I won't ask how many took the unit on nuclear energy. You probably did a unit on nuclear energy where there was a chemical reaction where there was a loss of matter in the reaction. Right?

Student: The energy is transported.

D: But your teacher said don't worry about that, it's gone. It's just transformed into what?

Students: Energy.

D: Energy is what they say. It's just transformed into energy. Well what's energy? You've all read Einstein's theory of relativity. He gave a famous formula. What was his famous formula that you used to spout off in junior high to show how smart you were?

Students: E equals m c squared.

D: What's that? You don't know you just said it? What's e equals m c squared? Dale?

Dale: Energy equals the mass times the speed of light squared.

D: Energy equals the mass times the speed of light squared. What does that mean? It works. You don't ask questions. You just do it. Never ask questions, never complain, always obedient, just always ... You've heard that at home. What does that mean? In very simple terms. What does it mean? What does it suggest to you even if you don't know what it means?

Student: Energy ——

D: Basically it means there is some way of relating energy and mass. So when we say that matter can neither be created nor destroyed we just can't make something out of nothing and you can't lose it into nothing. And now we're into a situation where it happens well there must be a relationship between energy and matter into which you can change one into the other. Maybe you get the concept that energy is another form of matter. It's something to do with the speed of light, we don't understand it but we're bound by it. So if we throw in some fantastically large speeds we can get into this concept of energy that none of us really understand because it's back up in here. Something that doesn't make sense to us. Ah, what we're trying to get at is ah, these laws as you said Tony are things that are supposed to happen in nature under certain circumstances. Right? A law is a phenomenon, which is another word used to describe something we don't really understand. It is a phenomenon which always occurs under a certain set of circumstances. It's always the same. The law of gravity is always the same. You can measure, use it. We now know how to overcome that law or work around that law. You know we make space ships go out into space. We use some other laws. But these laws so to speak you will find, I hate to do this, is thoughts about unchanging laws, these laws we find we may not know all the laws. When we're playing around with energy transformation we have a bunch of pieces to a jig-saw puzzle, but we're missing some of the pieces. --- I know when I turn out my jig-saw puzzles it gets very frustrating when you can't find all the pieces. Because there is that beautiful picture but it's missing somethings, right? And you get frustrated. And that's sort of the way you might feel about this unit at times. That some of the pieces aren't there and I'm sorry I can't give them to you, because we haven't found them yet. But I very much think there are all the laws to let us understand this available if we can just find them. this law says that matter can neither be created nor destroyed only transformed from one form to another and that includes energy. So there is a direct relationship between these two things. As we look at a living system that system can make some transformations between energy and matter eventually and continue to live. The first law then of thermodynamics said matter cannot be created nor destroyed, but only transformed from one phase to another. To give you an example of that, that is very effective (rubbing hands together) we can take potential energy and we can convert that into kinetic energy. We have transformed potential energy into kinetic. What have we done?

Students: ---.

D: O.K., O.K., we can take something that isn't burning and we can burn it. And that's transforming potential energy of the substance into kinetic energy. What's the difference, quote difference you learned in junior high school?

Student: Potential energy is sort of locked in.

D: Stored energy.

Student: Kinetic energy is

D: Stored energy releases food. Right? The term kinetic we've used to refer to movement right? So changing potential energy to kinetic, we're changing a stored form of energy into a moving form of energy. It's sort of like taking an atom and speeding it up so it becomes energy. Whatever that concept is. In a nuclear reactor. Right? So we can transform, we can change different ah pieces of matter into different things by performing chemical reactions. But all this tends to be bound by the concept that under normal conditions you're not going to take away any atom and break them up and rearrange them. And this living system follows that law very well. Take a look at cells. You don't just create matter out of nothing inside a cell. And we don't lose it out of nothing, er lose it into nothing. The cell follows this law very obediently. You find nature by and large is very obedient. We wish sometimes people were as obedient. Ah, it follows the rule that says you can't lose matter and you can't create it. And so in the cell we find this law is followed pretty well. There's one other concept that's there that —— she'd like to explain to us and that's the second law of thermodynamics. It gives us some understanding a little more understanding as far as energy goes, is concerned in relation to this first law. What's the second law of thermodynamics? This is the one that is really important for living things.

Judy: ——.

D: Can everybody hear that?

Student: No.

D: You'll have to say it louder.

Judy: I said heat cannot by itself cannot pass from one body to another body, i. e., something ;that is hot cannot make something that is hotter than it, more hotter.

D: Got that Rick? So what is another way of saying that Judy.

Judy: ——.

D: She is saying that heat flows from hot to cold. O.K., time for me to again remind you of a chemical concept that heat lost equals heat gained. We've all gone through that. It doesn't go from the cold object to the hot object. It always goes from the hot to the cold. There's another way of writing this down but it —— another way of describing the second law of thermodynamics. Lorna?

Lorna: ——.

D: O.K. Ann go ahead.

Ann: I just, I just, the heat goes to the cold object, Do they balance out completely?

D: They move towards an equilibrium. Ah, sort of. Sort of. Instead of belaboring the point. Which way is that Dick. The same word you didn't get right on the last chemistry test. What's entropy? What is it? You always like using these big words. What's entropy, Terry?

Terry: It's when --- goes to randomness.

D: O.K. Create randomness or everything moves to the situation as Ann said an equilibrium or a randomness. O.K., so things tend to become more random, as they move towards equilibrium. And what was equilibrium again? I asked this a long time ago. What is equilibrium? Sid? It was so long ago. Lillian?

Lillian: Um, a combination of ---.

D: We've used the word as far as concentration gradient is concerned. Where we had equal numbers of particles on either side. In the universe all things tend towards randomness, naturally. What does that mean? Dave? What do you mean when you say in the universe, it's up here, all things tend to move to randomness?

Dave: Well things try to spread out so they take up all the space and their own space at the same time.

D: O.K. that is one theory that ---. That's there's a spreading out to try and fill the entire space. Basically what we're trying to say is everything tends to become more disorganized. Randomness is disorganization. It is the state of disequilibrium. It is the state of equilibrium where everything is spread out equally. There can't be any organization if it is spread out equally.

Dave: But if it's spread out equally it's organized then.

D: Ya, I suppose. You can take all the --- page you have there and take a look at a page from you text and take a look at all those words on those pages and have them move toward equilibrium, or in effect shake them all up so they're all randomly distributed and they'll have organization that, that ah ---.

Student: ---?

D: You do have a type of organization called randomness. Alright. Things tend to become less organized. Except where? Let me back up. I said naturally, and I tried to emphasis the word. In a natural condition things tend to become more random. What effect does the natural have on this concept? Bill?

Bill: ——.

D: What's the nature of this. That's what I'm trying to drive at.

Student: Things that are forced to be, or do a certain thing.

D: O.K. we're eliminating the use of energy. Is that what you're saying? As we talk about force. Things just happen. what I'm trying to drive at is that there must be a law in nature that puts everything toward equilibrium. We talk about laws of diffusion, we talk about osmosis as an expression of that law. Things move to, well all over the place. That would create a situation of randomness. Now did we find, as far as osmosis is concerned, that that always continued, as far as the cell was concerned, until there was equal concentrations?

Student: Well if everything's becoming more random, how come we have laws of nature? If it's random we can't really have a set of rules.

D: You can have a set of rules governing the moon, the world's randomness.

Student: O.K. the whole universe is becoming more and more random, eventually there won't be any law.

D: Eventually. That's true. And when we get to the end of the universe. When we get to an understanding there is no end is there? You can't eventually get to something if there is no end. So those laws will always exist, unless we find some other laws that might be able to overcome or supersede or change the effect. O.K. What I'm trying to drive at is living things don't follow those laws. Living things don't become more disorganized, do they? Does the cell move towards disorganization, towards equilibrium? Did osmosis continue until the water was equally spread out on each side of the membrane? It stopped. And what did we call that situation where there was no net change? It wasn't equilibrium. We used the term, to give us some idea —— understanding. We talked about, and we used this term and there was another term that we used ——. What is the other term? And both of these terms give us the idea that there is no net change. Fact that is was not equilibrium. It was not equal amounts on either side. There was no net movement of water. There was still more water on the outside than the inside. There was no net movement. Some other forces come into action. Just using that term, gives us the idea that to stop moving things towards randomness you have to apply some force, or apply some energy. If you don't apply the energy what would happen? Sam?

Sam: You'll have to go back.

D: It'll follow this law. Unless you apply another law this is going to happen. Right. Now one of the other points I'm trying to drive at is, as far as this is concerned you and I as a living system, very small, very insignificant ... The length of our total lives on the earth is very small in consideration to what everything has been. Therefore the condition of life is momentary as far as everything is concerned, is a momentary period of time wherein energy can be used to keep you from moving toward randomness. It's only momentary though. Because as soon as you stop applying the energy or following the law that says energy is used to do work, or build or synthesize, as soon as that stops, we'll have ... What happens to you? You stop utilizing energy. You die. What happens to you or the matter that makes you up?

Student: ---

D: What happens to you and all the atoms and molecules that make you up?

Student: ---

D: You begin to be broken down so to speak. And you move towards randomness. Right? Finally you've had this thought passed on to you before, that the atoms and molecules that make you up are the same atoms and molecules that made up some plant at some point in time perhaps made up some other living thing. O.K. Because we believe this first law that says you've got to recycle matter. So every matter that makes you up has got to have been from other organisms or whatever and it's just been re-used. And as you eat things, you're eating atoms and molecules that have been around. --- O.K. and so the point that I make is, isn't it nice for us to be able to determine or use some other laws. That's why I say the jig-saw puzzle isn't complete. To apply some other laws and to say ya, life is a little more unique than these other laws suggest that it is. And the key concept is this, that in order for you and I to exist we must take from the surroundings energy, and use it. And as soon as we lose the ability to take energy and use it then we will begin to follow this law ---. Yes?

Student: How come you have --- a closed system?

D: Who said it's closed?

Student: All our molecules and stuff go to form other organisms and we eat other organisms. And it's all being recycled. You can't have really have randomness because randomness works outside of them.

D: Well, well it's like taking the words on your page. Shake them all up, you still have all the letters but it's a different rearrangement. And that's the concept I've been driving at as far as things are concerned. What I'm saying to you is, that is it a closed system?

Student: Well ya, well where else would ---

D: --- transport energy that I mentioned in the nuclear reactor situation. Does the energy have to stay on the earth? Does the heat loss get into space? What is heat? We run into a problem here. Heat is supposed to be the movement of molecules, but as soon as we get outside the atmosphere we say there are no molecules. There we go. Well, I had a scientist come in one time and try to tell us all about light. What it is. Now it was humorous because we knew just like he did that it's kind of hard to put your finger on. To find a definition of what it is. Is it a wave, is it a particle? What is it? The point I'm driving at is we call these laws because we see in certain circumstances that they, that things appeared to do what this law says under certain circumstances. Change the circumstances and you may, ... That doesn't mean the law still doesn't apply. It's just you've changed the circumstances, you've changed the players it may be different laws have a greater effect than this one. Before I get too far into this, but I want you to leave this by you saying in your mind that living things, the cell is capable of overcoming, or superseding or not following, the second law of thermodynamics for a period of time while the cell is, while the cell incorporates, uses, transforms energy in order to do work. That is the cell as the basic living thing does work as it utilizes free energy, you're not moving towards randomness. You're moving away from it. You're moving towards organization. Now please keep in mind these are only some of the pieces in a jig-saw puzzle. They're not all there. O.K.? There are, quote, laws of nature. And the more we learn the more we realize that as you put these laws together to make different things it seems sort of silly to think you can overcome or destroy both the law of gravity, yet we see airplanes fly all the time, does that mean gravity isn't being obeyed? Well it is but there are other laws that are being used in that particular situation.

Student: You say we don't follow --- ?

D: Momentarily, quote, life. As soon as it's not living do we follow the law? Ya, we do. So this condition of life, this quote metabolism, the ability to metabolize means what? The ability to use, transform energy and use it. Alright? Does that make sense? If you and I didn't use energy we wouldn't be here. That's how important energy is. Now, I want to say number three. O.K. let's go on here. Now we're going to try and separate out the universe and take a look at a small part of the universe that pertains to you and I, O.K? Mainly ...

(end of tape)

Where did sun come from? We don't want to get into that. It starts in the sun, as far as you and I are concerned. Radiant dinner. You'll probably run out of space too if you're drawing as big as I am. ---. ---. O.K. The sun radiates energy out into space. Part of that comes down to earth O.K. What happens to the energy that hits the earth? That enters the atmosphere? Terry? Whatever this energy is.

Terry: Some of it bounces back.

D: Some of it bounces back off of what?

Terry: Off the atmosphere.

D: Off the atmosphere. Bounces back into space. So it never does get to the earth. What else happens? Lise, what happens to some of the rest of it?

Lise: ---

D: Some of it goes through the atmosphere. Causing molecules of the atmosphere to speed up, right? Very good. What else happens?

Student: It hits the earth once it gets to it.

D: Some of it actually hits the earth, instead of being diffused in the atmosphere and begins to do something to the molecules of the land, the water. It speeds them up. And what else happens to that energy? It's absorbed? Is that what you said?

Student: It's used by the plants.

D: O.K. it, that energy, also as it strikes the plants for example, it's used somehow. O.K. And then what else happens to that energy? Then some of it bounces off the earth. Just like a mirror it's reflected back out. Right.

Student: Some of it is stored by plants.

D: Some of it is stored. Before it ends ... Well what happens to it ultimately? Does it all go back into space? Ultimately. But for a while it's stored. Lane, of course is moving us back on track. Thanks Lane. Some of it's used by plants in a process we call autotrophic nutrition. Right? What happens at this point in the energy? In general terms. Anything happen to the light energy as it's incorporated and used by the plant?

Student: —

D: We said it was stored right.

Student: It's incorporated —

D: It's incorporated as you said into something. Right, it's transformed. It's not light energy anymore. It's now what? It's now what we term food energy. Right. So the light energy is transformed into what we call food. that may not be the best way to — it goes a little beyond food. Sandra, what kind of energy does the light become?

Sandra: It becomes potential energy.

D: It becomes a form of potential energy called? There's lots of forms of energy and this happens to be one of them. There are five or six different kinds. You said it made a molecule. It's stored in a food molecule right? And becomes a form of chemical energy because we're making quote food. And that food molecule that didn't exist before is being made by the addition of some energy; therefore, it's stored as a chemical energy in the bonds between atoms of what we call food or the actual name is glucose. O.K? Let me make a very important concept for you here before you go for your break. As we go from the sun down to the plants and as we transform light to chemical energy we should make a note that not all that energy is transformed into chemical energy as you mentioned some gets bounced off, some gets absorbed by the earth and so forth, and some of this is lost into space ultimately in the form of heat. And that serves to ...

(end of period)

Autotrophic organisms ah, plants; therefore we have a conversion of radiant light into quote chemical energy that's found in bonds of ah foodstuff. Alright so now we have chemical energy. Alright, the process by which this takes place is the subject of this unit on photosynthesis. But what happens to the energy now since all things are not autotrophic? Jim?

Jim: Our energy is taken from the autotrophs and —

D: O.K. the consumers which we will group together as the heterotrophs. It's probably not the best way to write this down but you get the concept. I can carry on with heterotrophic nutrition. Now, what happens as far as energy is concerned in the heterotroph? We take this energy that was one time sunlight and is now in the form of chemical energy and what happens to it Holly?

Holly: —

D: O.K. quote burn. O.K. Try not to think of a flame.

Student: ---

D: Excellent. O.K. it's chemical energy but it's stored. Right, so that's potential and I'm sorry you can't all see that over there, but you heard it. That chemical energy was in the form of potential. It was stored in a molecule which we will learn was glucose and its derivatives. And what happens is that energy is transformed into chemical energy. But now hopefully in some way, shape or form into kinetic energy or it's used. And we will talk about the utilization of chemical energy later on. So we get an idea that some of that energy. Does all of this energy end up down here? Why not?

Student: ---

D: How do you know some of the energy is lost?

Student: ---

D: Well that was lost up here, right? We talked about how it was lost. Not all of it got to the plant. Some of it was reflected back into space, some of it was absorbed into the atmosphere. So a portion of quote, all the energy in the sun, was picked up by the plants. My question is, is all the energy that was picked up by the plants converted into chemical energy? Is that passed on to heterotrophs? ---. Dick?

Dick: ---

D: Dick said some of this energy might get burnt like in a forest fire.

Dick: No. The plants will get burnt.

D: Oh, the plants will get burnt in the forest fire and then it's lost into space before we can eat the tree.

Dick: Yup.

Sam: Um wouldn't it take energy to convert energy into chemical energy?

D: Another good question. Isn't there some energy used in converting light to chemical energy? Ah, I like Dick's the best.

Student: The way Dick's goes it doesn't even get to the heterotrophs so ---

D: But, but I described it --- hung up on the sports car part of it. Dick's idea was, was a good idea. What he was saying not every single autotroph is eaten by a heterotroph. Some of them live nice and quietly in the forest and just die. And if they die what happens to them? They're broken down by bacteria and some of the energy is lost into space. Lost in space, that was a good movie. —— And you get more energy.

So the point that I'm making is that heterotrophs obviously derive the energy that's needed for them from the autotrophs. And depending where you are in that food pyramid you're going to get more or less energy. Depending on how many things you have to go through to get the energy, because at each stage the energy is transferred some of it's lost. So all you meat eaters, that's why you're all going to become converted to vegetarians. You want to get the direct source of energy rather than go through some cow. Ya that's right. Never thought of that. So much for Macdonald's at mid-term breaks. ——.

Student: Does that mean you have to consume more?

D: That would mean you would have to consume more if you're further away from the source of energy to get a certain amount. Ya that's right.

Student: Would that [ah...

D: [Does that mean you'd get fat? No.

Student: Would that have an effect on the size, over a period of a million years, on an animal?

D: This is getting back into Biology 20. It's been a long time. Yes there is going to be an effect on the size of organisms. That's why there are fewer organisms at the top of the pyramid than at the bottom. Because they are further away from the source and there isn't just enough energy to support them. Dick?

Dick: Does that mean that you could eat less if you just ate the plants?

D: Well that's what some vegetarians think. But they're all skinny guys. Alright from the heterotrophs what happens to energy? Is it passed on?

Student: Ya.

D: How?

Student: Well you can pass it on to another heterotroph.

D: Ya, but this is the whole pyramid. What happens to energy here? Isn't it the end so to speak? From here this is quote for you and I, let's be specific. This is life. As long as it's coming down here we're alive. Once it gets broken somewhere we would die. Because the ecologists think —— affecting all this population will have a net effect on us somewhere down the road? Well as long as we're getting it we don't mind. But when life is over whatever energy was possessed in the body as far as building things up is lost in space as we're broken down. Basically it's ——. Alright, the process here that —— spend another week or son on, whereby this potential energy is released so that you can use it and do all those cellular processes is of course respiration. Whether it is aerobic or anaerobic we will be looking at respiration. How do you get the energy, how can you use it? I think you'll see this unit, as far as energy transformations is concerned, takes from now until the end of March. If we look at the whole range of energy transformations. We're going to do energy transformations number one, which is photosynthesis. Once we get through this we will go to energy transformations number two, which will be cellular respiration. O.K.? Any questions? [3 s p] Alright concept number one, concept number two. Very important that living things in effect use energy so that they don't move toward randomness. And number three gives us some idea as to how energy does flow towards these living things and how they use the energy in order to live. Now with respect to the matter there is also a flow of matter. As we teach it to you. And I threw some questions in on that earlier on this week. As we teach it to you we tell you there is a cycling of the matter. That there is a finite number of hydrogen atoms that have always existed on the earth and at least exist now and they're being re-cycled. Being used over and over again in different things, right? So this energy flow is a one way flow. We're moving from the sun which releases energy, that energy we can call free energy because it is available to do work as far as living things are concerned. Or moving away from that free energy toward entropy or randomness where we don't have the ability to use the energy. Now, as far as matter is concerned we look at a cycle especially as we look at processes from here to here. What's one of the substances that's cycled? ——. Natural cycles? What was one of the substances?

Student: Nitrogen. Oxygen.

D: Nitrogen, oxygen. Autotrophs evolve oxygen. They release oxygen. What does a heterotroph do with the oxygen?

Student: ——.

D: It does something. Forest fires, whatever, burns it and releases energy, right? And when you breathe out, you're breathing out something that wasn't there before. At least in the same concentration. You're getting rid of something called carbon dioxide which just happens to be used by the autotroph. And that autotroph takes the carbon dioxide and puts it together with something else that animals want. That other things give off. And that is water and it uses that carbon dioxide and what does it make? Well it makes that food thing that we were talking about earlier on which we called glucose but I'll just draw it as a carbohydrate. And that thing is used by the heterotroph to get the energy. And so we have basically four substances that appear to be cycling between the autotroph and the heterotroph. Plus the key in that is the energy. Now that flows one way. So energy flow is unidirectional. Matter flow is cyclical. Now, got all that? Now why are living things living? Why are living things appear not to follow directly, at least while they're living, quote these laws of thermodynamics? Well, why don't living things appear to follow these laws of thermodynamics? What do they do? They go against this law that says things move towards randomness. ——.

Student: ——?

D: He said because they're capable of transforming energy and using energy. O.K.? That's what this whole unit is going to be about. Transforming energy and then using it. By unit I mean energy transformations. O.K? Now we spend a lot of time on these two processes and you're goin' to ask yourself who are those crazy scientists that print all this information so we have to learn it. Ah, and the reason we do it is this, in order to appreciate the condition of life, the condition of bein' able to metabolize, we should be able to appreciate very much the role that energy plays in allowing us that condition. Like when you were in junior high you watched the film ——. Turn off the sun and it won't take very long before ——. Because it is the major source of energy. Most of you don't really have a whole lot of interest in plants, but very much interested in how they make food. So that I can have some source of energy to live. The whole process, which means we will be looking at plants, how they're made up, how all this takes place plus the chemistry part of it is very important. Very, very important. ——. Now these are the three major concepts that I want you to get. The whole is all about. There are two concepts that we haven't covered that I like to talk about now at the beginning because it tends to make a little more sense now ——. And these two other sections are closely related to each other. And they related to the system by which the energy is transported. Now you've heard this term before and I mentioned it once and said we'd come back to it to talk about it a little more.

We're going to talk about this chemical energy. There is a molecule in living things that acts as a transporter of energy, chemical energy. It's called? Can anyone remember? ATP, right? Over here when we talk about energy coming from the sun and we will find as we go through this unit that if that energy can be converted into light energy and chemical energy then living things use the energy. They don't use energy in the form of light. This system of transporting energy then could potentially be a product of autotrophic nutrition, if the cell can produce ATP then it has converted light to chemical energy and that ATP can be transferred from plants to animals and we could live very nicely. Which means this is a molecule that is produced from this process. Or it could potentially be produced from this process. Alright, and so as we go from here to here we talked about food being transported but we should also talk about ATP as a molecule being formed to transport energy. Now what is ATP and then we'll talk about how it's used. This is a very, very important molecule as far as light and the ability to metabolize is concerned. This is the basic molecule that carries the energy by which the cells in your body are capable of metabolizing food. And ATP is adenosine triphosphate. You have the chemical structure ——. But what this is, and you'll recognize this, is a molecule called adenine bonded to a ribose sugar molecule bonded to a phosphate group, bonded to another phosphate group, bonded to another phosphate group. Recognize what that is?

Student: ——.

D: Very close, very close. If I cover this up what is that molecule? That's a ribonucleotide.

(end of tape)

If there's ADP and if there's phosphate and if we throw in energy we can charge it so to speak and make this. The process goes in this direction is called phosphorylation. Which means adding a phosphate group, a high energy phosphate group to ADP, producing ATP is a phosphorylation reaction. It's a reaction where we produce an energy rich molecule from a molecule that was lower in energy. You'll never guess what it's called going the other way. Dephosphorylation. Alright, now what happens if I ripped off one more phosphate? What would I be left with? I'd be left with adenosine monophosphate. This was ATP, this is ADP and as I've gone down what have I done? I've changed one to the other. I've lost energy here. Is there energy here? There has to be or otherwise there wouldn't be a bond. It's less than here ——. Alright there is less energy, as you go from here to here to here there is less energy. It is harder to do but if you go from here out to here what are you going to do? Store energy. So the concept that we're trying to drive at is this molecule is energy and as it moves it's got energy available to release. Normally you look at it here. That's the normal situation. Now this process becomes fairly important as we apply it over there. If this energy is light energy, like when we talked about photosynthesis, what is this process called? If this is light energy that is used to build this plus the amount of energy what is it called? Jim?

Jim: Photophosphorylation.

D: Amazing. Photophosphorylation, that's right. People say you're smart but they don't ——. So photophosphorylation would be the process if this were light energy. What if this were chemical energy? What would that be called? What if it were electrical energy? Well that would be carrying it too far. What I want to talk about in this unit is a process called photophosphorylation. It just means using light energy to produce an energy rich molecule called ATP. It is a phosphorylating process where you add phosphates. O.K? ——. Alright where are we then? Any questions about this system? A very, very important molecule. It is the basic molecule that transports energy in both animals and plant cells. There is one other carrier molecule that we want to mention. And this is part of the, this is part of what I like to call part of the electron transport, transmitter ... You remember we talked about the two types of chemical reactions that take place in living things. What are the two types of chemical reactions that take place in living things? ——. Ion exchange and redox, right? We said the ion exchange were those reactions involving the transport, transfer of electrons. Acid base utilization to maintain a constant pH type of reactions and then redox reactions. And how did we classify redox reactions? They were —— involve electrons being transferred from one thing to another. We went through all the oxidation reduction reactions. What kind are they? They are the energy reactions. Right. We're going to talk about energy here so we have to talk about electrons and hydrogen and the transport of electrons and hydrogen from one to the other. There is a molecule that acts as a transporter of hydrogen. it's called? Nicotinamide adenine dinucleotide or otherwise known to its friends as probably ——. You also have a chemical formula a structural formula in I think it's chapter eight of your text. I wouldn't spend a whole lot of time memorizing that. This is a very interesting molecule because it is like Dale says a cousin, not to Dale but to ATP. See this particular molecule just happens to have adenine in it, just happens to have ribose sugar in it and just happens to have a phosphate group. It's a lot like AMP. Now to make ATP what did we add? Well we added some phosphate groups. Well it just happens to be a phosphate group and because this a cousin this is a little bit different. Instead of a phosphate group there is another ribose sugar. Now that should take care of the adenine and most of the dinucleotide. We said two nucleotides. Well this is one of them and this is part of the other one. And you'd expect there is something bonded to the ribose sugar. You'll never guess what it is. Well what's left? Nicotinamide. Like that. O.K. Nicotinamide. This molecule is a lot like this one, very similar. A little bit different. This particular molecule transports electrons away from, transports electrons and/or hydrogen away from substances and towards oxygen. Alright ——. It transports electrons and/or hydrogen all depending, we'll talk about how we're going to use them interchangeably, it transports these towards oxygen or towards a strong what? ——. A strong oxidizing agent. Now in all the literature that I've read there is another form of this. It has an extra phosphate group in here. So you'll never guess what it's called, Nicotinamide adenine dinucleotide phosphate. NADP. Just so you won't get confused with Northern Alberta Dairy Pool in the course and in your textbook and that's the major reason it never talks about NADP. It always uses NAD, whether it is this form or whether it is with the extra phosphate. The major difference between them is where the hydrogens and oxygens go. Is it going towards oxygen or the strong oxidizing agent or whether is going away from oxygen? Excuse me the oxidizing agent. ——. So this is the major system we'll keep in mind. NAD. You might hear it in some of the audio-visual stuff we might do. It's virtually the same thing. NAD and NADP are virtually the same thing. And potential for carrying hydrogen. And so this particular molecule then will move electrons or hydrogen ——. I'm sure the reason that Sid said this shouldn't be a B, instead of an N is because he knows something more about this than the rest of us. What is that Sid?

Sid: ——.

D: Sid just happens to know somewhere down in his subconscious that I suppose a B would be O.K. but it doesn't fit with the NAD so we put in. This thing is one of the B vitamins. I'm sure Sid was trying to spur us along ——. So the reason I mention that is it gives you a little added reason to recognize why you should take a serious look ——. Make sure you get ——. This is one of the products.

Five concepts that only took us two periods to get through. Five concepts that I want you to grasp from the beginning. And I know I have probably spent a lot more time than I should have. I really think it is really important to get a basis. It is unfortunate that you've got this unit and you start off with —— not slightly confused but ——. It make it much more difficult. Five concepts. Number one, the universe, whatever that happens to be, everything is made up of the universe. A very unique condition plus everything that's around it. Life is a very unique condition found in the universe. Number two concept. That there are quote some laws some rules that govern the interactions of things in the universe that all things under specific conditions follow. The first one of which we already know. The first law of thermodynamics that matter can neither be created nor destroyed, that energy is constant. As you transfer energy from one thing to another there is a loss. O.K. that concept which gives us some degree of finiteness to understand. The second law that says everything moves towards randomness. There are important laws that govern a lot of these reactions that take place right? Diffusion and osmosis take place because of this. The third concept which make life unique that was in this one-way flow of energy there is a unique condition where we cycled matter and we utilized the energy to go up against randomness or disorganization and actually build things up. And you grow, and that's the wrong way. That's not towards disorganization. You become more complicated. Alright, under natural laws and you've probably had this explained to you a thousand times before. How many chances are there according to nature in which you can take all the parts of your watch, throw them in a box, shake it up, and when you open the box there's your watch?

Student: It could happen.

D: According to nature that's not natural. That's not according to the second law of thermodynamics. Things don't get more organized they get more disorganized. But life is a situation where things do get more complicated. A human being is a very complex organism. We started out as one cell, not very complex in relation to what you are now. So some where in this flow of energy there is a unique position where matter can be cycled, which is sort of a side point. It gives us an intro to photosynthesis. But where energy can be used to build up things, a synthesis. You and I are very unique in that respect. Life is a very special thing. It's hard to describe what life is, but the ability to metabolize is a very special ability. So this process by which you and I metabolize by which and get this energy is a great process. Because eventually we're going to die. We all are. And everything will fade away. And whether that ever ends I don't know. That's getting back into the universe again. So you'll end up someday in the universe. But you and I don't know now, this is food for thought, is this an eternal cycle? An infinite cycle? Does this randomness become organized? Again ——. That's the third concept. The fourth and fifth concepts are back to the more mundane. That is in the living system there are some transporters there are some things very highly evolved in this energy transformation. Two of which are ATP, essential. I don't know on how many tests you will find this that we have asked, tell us all about what it does. It is a very important molecule. And NAD which is really important in the transport of electrons and hydrogen. Here we have simply, quote energy, transported into a molecule between phosphate and the molecule. Here we have the transport of hydrogen and electrons. This will help us understand how matter is cycled. That should do it for today's class.

APPENDIX E

TRANSCRIPTION OF THE INFORMAL DISCUSSION HELD WITH TEACHER "A"

B: Ah, if something catches my interest as we go through, ah then I may vary it and pick up on one of those items. O.K., ah, just for some background can you tell me, ah did you graduate with a B.Sc. from the U of A?

A: No, I have a B.Ed. and M.Ed. from U of A.

B: And so, in your biology training what kinds of areas did you specialize in?

A: Ah, it was really a general picture, sort of. Botany, zoology, 1 genetics, ah, 1 chemistry course and no physics so, some math, 2 maths and some music.

B: So a very broad range then. Have you done any scientific research? In biology or chemistry or anything?

A: No, not in the professional sense. Only as projects in my courses.

B: In your classes. Alright. In, how long have you been teaching biology?

A: Twenty, 19 years I guess.

B: So, in ..., have they all been here in Edmonton?

A: Yes, since '64.

B: And so, you would have been what, teaching Biology 30 for almost?

A: Almost since the start. I started teaching Biology 30 in '65.

B: Um, huh.

A: That would have been the fall of '65.

B: Alright. Did you end up taking any specific courses in either the history of biology or the philosophy of science at university?

A: Not in history of science. Um, just a senior level science curricula course offered by Dr. Nay and at that time Dr. Jacknicke. Um, that was 580 or something like that. I forget the course number.

B: I don't [know.

A: [It was a seminar for grad students, in ah, science.

B: And what, they dealt with the philosophy of science in that or

A: Yes.
I remember Schwab and some of those people we discussed in a seminar setting.

B: Did you get into people like Karl Popper and

A: No. That has shown up since, as far as my reading is concerned.

B: How about Kuhn, Feyerabend, Lakatos?

A: Don't remember any of those.

B: Any of those people?

A: The only reason I recognize Kuhn is what I've read since. I can't remember, that would have been back around '69 or '70 I guess.

B: Right. Like Popper was back in the '20's and '30's.

A: I don't remember.

B: Kuhn, his book came out, the original one, in '62 or something so

A: They should have been part of it and maybe they were but I've just forgotten.

B: Well, I would suspect that they weren't part of it. When did you do that class?

A: '69.

B: '69. I suspect that it is something that has come to the university more recently than that. Well, now what about any nature of science? Do you make a specific point of dealing with that issue in your biology classes?

A: I do for about two periods, one and one-half to two periods at the beginning of the course and my thrust at that point is simply to say we are limited in what we can study in this course. Science is a limited way of knowing and secondly it does not produce truth. And those are sort of my two thrusts. Um, so if we run into ideas in this course that seem to be in conflict with some other ideas we have, the student has picked up along the way from a different way of knowing, it does not necessarily mean to say that what we're learning here is sort of ah, more or less true than what you've learned in some other area. In a sense you can look at the world from different angles and see it from different perspectives and both are legitimate. And I'm trying to reduce the level of threat, particularly keeping in mind those students in the class who come from, from ah, a world view greatly influenced by fundamentalist Christianity.

B: Right. Do you identify that as the nature of science to them?

A: I'm not clear on what you're asking?

B: Well, when you're dealing with that material in the [class

A: [Oh, Yes. I see what is science.

B: Do you entitle it that?

A: Yes.

B: Because, interesting enough when I had them do those questions for me this morning I had heard that you had done this with classes and I don't know if you had actually gone through that material with that 30 class that I had observed. But I mentioned your name and Smith and Jones as three people who I had heard who do this. And I said if they had specifically had this instruction given to them they should indicate on the sheet. And when I went back to the university I looked at those forms and not one of the students out of this class indicated that they had that material from you.

A: Not one?

B: Not one.

A: It isn't getting through.

B: I think it is getting through in some of the discussions that I had with certain individuals in the class, but with others I would say it is not getting through. So, that was interesting. The other thing that I noticed about those forms was compared to the other two classes many of the students in here have not had any chemistry or any physics. And that was just an observation on my part. You know I'd actually have to sit down and count.

A: No Chemistry 10?

B: Not even, in several cases, not even Chemistry 10.

A: That's surprising. I would think there'd be only one but again my memory, I get this class confused with the one I had last semester so my experience is that students coming into Biology 30, out of a class, one or two come without any chemistry in high school what so ever. Sometimes that's because they have transfered in from another [province.

B: [Province or something.

A: Many of them come in with Chemistry 20 and at least a third of this class has Chemistry 30. I find it very puzzling, the response here.

B: I can actually go back and count but I just sort of skimmed through the file and there were quite a few that had chemistry but there were quite a few that indicated they didn't have any. And physics was [definitely

A: [Well, that doesn't surprise me.

B: very low. Now, something that you have done in the class that I noticed was you made a specific point of teaching the history of biology as you went through that section. And do you normally make a practice of doing that?

A: I would say that on this topic I normally do. And on this particular topic, for some reason I emphasize it more than other topics. Because the book presents quite a few men in the treatment of the subject and secondly I guess I find it an opportunity to see progression more clearly than in some other fields. Maybe just because I'm aware of it. But you can see how ideas grow. Starting quite early and how they progress and become more and more complex and more complicated. And how the level of experimentation then becomes more complex as time passes. I think it is an opportunity to point that out. Whether the students get that I don't know, but I definitely was trying to say O. K. the first questions that were asked and the way they were answered was certainly different than the questions being asked now and the way they're being answered now. Or the way answers are being sought now. Starting off with simply growing plant versus radioactive tracing.

B: Alright. Why do you feel that the history and the philosophy behind those experiments is important to offer to the students?

A: Well, I suppose one reason is to show that curiosity concerning nature has been around for a long time. It isn't something new and that it communicates something about how we satisfy that curiosity, how we go about finding answers in terms of performing tests. And another reason I think it sort of relates to where our high school lab work is at in terms of historical development of the subject. That has intrigued me somewhat. The kinds of experiments or tests we do here as demonstrations or whatever are representing the kinds of tests and experiments that have been on the books for maybe a hundred years or maybe more. And where science research is at at this point in time in terms of doing experiments that represent the forefront of where science is at. This is so far removed from what we can do in the high school in many ways. I would like to see the students sort of in their own learning experience moving through history. We start off with concepts that are maybe two or three hundred years old and now we're working in an area that represents where science was about one hundred years ago in some ways. And to get up to the fringe, to get up to the frontier of where science is now, the kinds of questions they're grappling with will take some more work on the students' part. And maybe they don't want to wish to go there. Another idea, I mean to pursue it that far, to get up to the edge of knowledge so to speak. On the other hand you can point out where the edge was a hundred or two or three hundred years ago, well they have moved past that they already know more than what the general public or what the general science community, shall we say, knew at that time. That's kind of interesting to see yourself in history terms.

B: Do the students pick that up? Do they get that feeling do you think?

A: I wouldn't know because I don't test for it in that sense. And I don't discuss with them individually after. Maybe this is only in my own mind that, so I guess it's sort of like spreading your bread on the waters and you don't know where it is really going. I don't make a point of checking.

B: So you have something other than just, or you have a reason other than merely presenting the history as history? There is an objective behind your presentation of it?

A: I don't see any value in learning Priestly's name and the date unless I'm using that to communicate progression or how knowledge grows or how knowledge becomes more sophisticated or something like that. I don't see any point in just saying well, dut, dut, dut, through history with names and dates. No. But whether the kids are catching that I don't know. They probably say well I have to learn Blackman's name and I have to learn Priestly's name and I have to learn what they did and they don't see any value beyond that perhaps other than it might be on the test. I'm always confident that my brighter students, I shouldn't say I'm confident, I'm hopeful that my brighter students are participating in that, shall we say, second or third dimension to what I'm doing and enter into the larger ideas that I'm working at but maybe that's assuming too much. But the kind of feedback that I get from eye contact or facial expression or simply attention tells me some of them are travelling with me in that. I sure don't think the majority are. That doesn't worry me, because a heterogeneous class one has to deal at several levels and I would see that if I can engage three or four or five at sort of the broader picture I'm working at, fine.

B: Alright, I'll change tack here. Can you tell me what you think biological knowledge is? What is it to you?

A: Well, I think it is an accumulation of ideas or concepts that about living things, that have been developed over several hundred years. That's one thing it is. Secondly it's, you're talking about biological knowledge?

B: Um, huh.

A: Well that to me represents a body of information, but there is another dimension that would include the methodology and I'm not sure, I wouldn't put that under the heading knowledge in a sense.

B: What would you put it under?

A: I don't have the, well it's a way of knowing. It's a way of seeking, it's a way of searching. And it also delineates or defines the questions you're asking when you say biological. You are asking questions about the certain aspect of, of what this world represents and you're ignoring a lot of other things this world represents. So, biology would be a broader term which would include methodology, the kinds of questions you're asking. Ah, in contrast to saying biological knowledge that to me carries a more limited definition that would include for me primarily content or information.

B: O.K., you said something about an accumulation that has gone on over the years. That's important to your conception of knowledge?

A: I think it grows and changes, ya. It is an ongoing, this package if you like, or sack full or bag full of information keeps turning over or keeps changing. It is not a static thing. It is a dynamic thing. It keeps growing and changing.

B: O.K. and the other thing you wanted to contrast that with was biology as a way of knowing. I hadn't thought of it in those terms. So, I understand how you made a separation but on the basis of... For you biology would be a more encompassing word?

A: Yes.

B: Alright, in that case, is this biology or what I would term biological knowledge because I would tend to lump everything under the one word, is that a reflection of the world or is this created by man?

A: No, I think it has a smattering of reality, but a very, very poor picture.

B: In what way does it resemble reality? Or reflect reality?

A: Well I think on sort of the crude sense, bumping into a tree communicates something that is real. That is outside my own skull. The tree has separate existence to me. It is not a figment of my mind. And therefore, I do feel somewhat confident that there is something to treeness or something about treeness that I can know. Now, what I know, or my conceptions about what a tree is, certainly is very limited and I'm seeing that through a cloudy glass if you like. Well I think I have some notion, a little bit, a glimpse of the world out there and it isn't all the world within my skull.

B: But are your conceptions of say xylem and phloem, is that something we have created as biologists or is our conception an actual accurate reflection of the structures we call xylem and phloem in trees?

A: I would say, I guess have to say that xylem and phloem exist apart from me knowing about it but what I know about, words that

I use to describe it is very much a part of me.

B: Alright. That's the kind of question I'm asking. I wouldn't dispute with you that xylem and phloem exist outside of our existence.

A: They don't go out of existence when I go to sleep or don't think about them anymore. They still exist. What my eyes perceive when I see xylem through the microscope is certainly subject to interpretation. I've learned that because what students see and what I see can be so different. So what I bring to bear on that xylem from my experience is quite different than what a student brings to bear. And they don't maybe see the spiral thickening like I do. They don't see it in the three dimensional pattern as I might. But what they see, I really don't know what they see and therefore we have trouble communicating about it. But, there certainly is that individual aspect to describing and interpreting what lies out there. But I have confidence when I ask a student to make a cross-section of cells to look at xylem that more or less all of the students will have the opportunity to see the same thing. Now what they do with that opportunity will depend on what they bring to that occasion from their experience and their skill. But on that slide under their microscope there is more or less the same thing around the room. I don't know if that speaks to how you view things?

B: You're telling me that, I guess what I'm doing is interpreting your conception of biology so that it is separated into the factual component if I can use that word, plus biology as a way of knowing, a methodology.

A: Um, huh.

B: And in terms of that factual component some of those structures or those actually do exist but our interpretation of them is dependent upon our experience, various factors and so you and I may see the same object in reality but we will interpret it differently.

A: Yes, definitely.

B: Alright, now do theories accept what we accept as biology?

A: Do you want to give me a for-instance?

B: O.K., what I want to try and get at... Can we have what I would term biological knowledge without having theories or do we always have to have theories to consider this material as biological knowledge?

A: I really don't know if I can address that because I'm not clear on what's going... Let's see. So if we have a theory of evolution, let's say, do I need the theory before I perceive change?

B: Right. That would be an example.

A: Would I not see change if I didn't have the theory?

B: Right.

A: Which comes first is what you're asking. Observation and theory I guess. And for me personally?

B: Right.

A: Or put it in the unfolding of science as it has occurred over the years?

B: Try it for you personally and then if that differs for what you perceive as having happened in the science then

A: This depends on my creativity I think. I find it much easier for myself to once having had the idea, or having been exposed to the idea, then to see evidence for it when I'm out looking at the world, or looking at nature. But I think other are minds around who, when they see nature they start putting ideas together that we would say would eventually end up in theories. But for me it is much easier to go the other way. To read a theory, or to learn about a theory that somebody has put together or a group of people have put together and then to start seeing the world from this perspective. And then it makes sense to me. Do you want to ask the original question to see if I'm speaking to it?

B: O.K., what I wanted to know was whether or not the theories we have about biology, do they affect what we term biology? What we include in biology?

A: Yes, I think they do. Given this very extreme case of are species created specifically or are species evolved gradually over time. I think, depending on which one of those you espouse, you'll certainly put together your body of information in a different way. And I think this quite evident in the way textbooks are put together.

B: Now, if that's the case is that how science has developed over the years as well? The theory is generated and we then apply it to science? So that man has created these theories and he is causing science to be interpreted in a certain way?

A: Well, how can I say? I really can't put myself into the space of an individual scientist and know how he is really going about collecting his data, or what kind of blinders he has on when he is looking at the world. I can only speak for myself. But I think I do represent humans. I'm a human and I would then say that other people probably function somewhat as I do. Therefore on that basis I would say ya, I think scientists probably are seeing the world through glasses that are tinted by their theories. But I think the scientific community is so large and I think that it is international to the extent that people come at the world from different angles that there are built in self correctives. And from what I see in magazines and so on I would probably think that there is a safe-guard there. That people have to adjust their glasses and clean them now and then.

B: Do you end up giving that idea to the students in your biology class? Would that be one of the issues that you would address in the nature of science?

A: No, I can't identify anything I've done in the last month and a half that would speak to that directly. No, um, probably because I don't know enough about history that I could come up with examples. If you would pressure me right now and say well illustrate some knowledge we have has been sort of greatly influenced by a theory and therefore you see it presented only this way in the textbooks I'd have great difficulty doing that.

B: I guess what I'm really doing is asking whether or not you think science is affected by social factors?

A: Oh, definitely. Now how can... That's a gut feeling I have. But can I substantiate that? The only case that comes to mind, that's... One clear case would be the Lysenko affair in Russia. Now I know a little bit about that but not very much.

Side 2 of the audio cassette

A: Because I don't think the United States is pure in its research either. I would be suspicious because of who, you know, who is paying the bill. So if the big industrial, military establishment is paying for much of science in North America then I'd be suspicious that the scientists are sort of narrowing their focus and the way they look at the world. But can I document that with a case? No I can't. I'm just suspicious at this point.

B: Well I think that's sort of a current issue that has come up in science. Whether it is socially constructed as opposed to the activity that's often presented to students. And more and more people are going to the idea that they say yes it is socially determined and determined in a variety of ways. O.K., now when do biologists come up with theories? At what stage in the process do you develop a theory?

A: Well, I'd have to give you theoretical answer I guess. The word theory to me means a body of knowledge that explains a number of smaller issues. It's a larger framework from which one can speak to smaller issues and this formulates over time. To me the way I see it is one of the steps is a combination of observation and curiosity. And one picks up little bits and pieces of information, data or facts in the small sense which then raise some questions. These observations then generate the questions to which we will then propose or present the hypotheses which will then be tested. To me a theory encompasses maybe then several hypotheses that have been tested and have been examined for some time by several people or many people. Um, so I would see hypotheses, plural, generating a theory or formulating a theory.

B: Alright, what come after a theory then in that kind of scheme?

A: Well what you'll find in my biology textbooks eventually it may be a theory, it could be elevated to a law. And to me if that's the way it's being used the term law simply indicates a higher level of validity. Or it simply represents a more rigorous level of testing and therefore carries with it a higher level of certainty.

B: Is there anything after a law?

A: Not really. You mean in terms of even more certainty? No I don't think that science ever produces what one would call something beyond challenge or beyond skepticism. Ya, beyond the need for further verification.

B: Would that also be true, you've used the word fact in your description

A: The word fact I was using simply as a little bit of information.

B: O.K., to you even those kinds of pieces of information can be challenged and changed?

A: When I'm collecting facts I'm resorting to the use of my eyes and my ears and my senses. And I've lived long enough with my eyes to know that they play tricks on me. And what I thought I saw I didn't see. And also as we go from the world out there to the eye ball into the brain many things wonderful and weird can happen. And so what ends up in my brain as a bit of information or a fact is certainly open to challenge. And in that sense I do not believe anymore, maybe I never did, I'm not sure, but I've consciously come to recognize, at least at this point, that science never produces anything I would want to label truth, in the absolute, complete, whole sense.

B: Um, huh.

A: And I think as I, as you're participating in this ever accelerating growth, ah we learn that more easily if we would have 50 or 60 years ago. Ah,

B: If, if that's the case then how do biologists ah, decide which theory they should accept? On what grounds do they do that?

A: Well, to me it's sort of like a test, at least I'm really sticking my neck out on this but, how do I decide whether it's good music? And time is very important to me in that. I think time in science is extremely important and what happens to ideas over time is, is a good way to check whether something should be elevated to, pretty significant point or whether one should hold back and say well I'm going to wait and see about that.

B: I don't [...

A: [You don't follow what I'm saying [

B: [really understand your connection of time and the acceptance of a theory.

A: Well, I think a theory has been tested but it's going to be tested some more. If I follow my scheme of observation, hypotheses, testing and theory then I would think how much testing can be done is dependent upon how much time is available and how much time is past. And I'd see that as more and more time passes more and more tests have been done a theory becomes more authoritative.

B: So [

A: [In that sense time is required.

B: Do you see things like simplicity, common sense, the use of logic, um, moral considerations, political considerations, any of those kinds of things involved in your decision to accept one theory over another.

A: Common sense, I trust that. Or intuition, I think how does this particular theory fit into other ways of knowing. I shouldn't say, other bodies of information, other, other contributions that have been made by other fields or other ways of knowing. I think one continuously strives for a whole world and not a fragmented world view. And a theory, a new theory or a biological theory should somehow fit in or relate to some other ideas that, that are present. And one doesn't take them in isolation. And common sense would be one way of checking.

B: But, ah, the element of empirical testing is still the overriding way?

A: Ya, if it's going to be called science. Ya.

B: Do they do it on the basis of intuition do you think? Accepting or rejecting theories? See [that's

A: [I think that if I was seeing, well ideally I think that hypotheses are more clearly related to intuition than are theories.

B: We are talking about time and whether or not you will accept a piece of music as being worthwhile. That's what I thought you meant, that there was an element of intuition there. That you couldn't specifically say why music that has survived from the Renaissance is quality music as opposed to a piece of music that was written yesterday.

A: No. I guess I would suggest using music as a parallel but something of quality or worth will survive. I have that confidence. Now I don't know why, I just think there is something proven about something that is old. But maybe that is not correct. Just because a notion has been around for a long time, like the earth is flat, or the earth revolves around the, sorry the sun revolves around the earth, or it could go the other way too I guess, just because that idea was held for a very long time wouldn't necessarily mean that it was a good idea, I guess. So there I'm contradicting myself. But just the same, endurance brings with it some authority.

B: Alright. When biologists reject theories, right you have two theories and one is found wanting for whatever reason, is it legitimate to do two things to them. One add ad hoc statements to it to overcome these difficulties to keep the theory going for a while longer. And the second one is it permissible to add auxiliary statements to those theories you find that they have not specifically run into problems but if you add auxiliary statements that will improve the predictability of the theory?

A: This reminds me of something again from a different field. The parable sort of goes you don't sort of put new patches on old skins. You'd be better to sort of throw out the old skin and start with something completely new. And on the other hand if you have nothing better to replace it, I guess you got to keep it around with some patches on it for a while.

B: What about if you do have something better? Or what was conceived to be better by a certain group?

A: Well, if you're asking me as an individual to make a choice I have to go for this and not that. But maybe it isn't quite that simple. Maybe the old one has some good features about it. For example, dealing with this case of root transport, the root pressure versus the, you call that a theory, versus the TCT, transpiration cohesion. Now I can see merit in both those points of view and wouldn't want to be pushed to the extent that you've got to accept one and not the other. I'd like to have the freedom of hanging onto both and saying well this one speaks to this kind of a situation better than that one. But that one speaks better to these problems than that one. So I'd keep several going at the same time realizing that we don't have a complete answer at this time. And I don't see that one theory has to automatically exclude another one because no theory to ne is a complete description.

B: Alright. That question that I had there came from Popper in the '30's or '20's. Ah, he said that if you have a theory that gets itself into trouble for whatever reason and its found to be incorrect in an area you have to reject it and generate a new theory. What becomes of that problem?

A: But what if the one that you, has to, has a problem also? Well I would have trouble with that I guess with my understanding of how the theory, sure there must be some good, some worthwhile workable idea in that package that contains an unworkable idea or a poor one, that would still be worthwhile hanging on to. Or that you'd maybe translate into your new theory but you wouldn't write the whole thing off in a sense. You'd do some sorting and sifting and carry over some things. That's where I'd sort of see it.

APPENDIX F

TRANSCRIPTION OF THE INFORMAL DISCUSSION HELD WITH PAUL

B: I will ask you questions and then I will go away today with the tape recording of it and listen to what you have said. Interpret those comments and write a page. And I'll attempt to keep it to one page of comments. And I may or may not slip in a statement that you have not said, that you did not intend to say anything like that. It will be a purposeful attempt on my part to ah, include a statement that is wrong in terms of your thinking about biology. Now the reason I'm doing that is that I want you to do, when I bring this page back to you, is that you read it very, very critically and you comment on any parts and ask any questions about it. And I did this prior to Christmas with students and I found that if I didn't put in or potentially put in a statement that misleads or misrepresents them that they would just read it and say oh, ya, that's what I said. What I need is more than that. I need a critical reading of what I have said so that when I make my interpretation, to make sure that you really agree with what I have put on the page, and not just sort of pass it off lightly and say ya, that's what I said. And so I may or may not put in a statement. For example, in this page I didn't put in any statement like that. So, and could I get that back from you tomorrow?

O.K. what I want to ask you questions about, the aims of biology. The first one, can you give me your ideas about why we end up studying biology. What is the purpose or aim of it?

Paul: Well last year in Biology 20 you go through the argument of evolution and creationism and to me that is one of the main reasons for studying life and find out eventually where we came from. Originally why we're here. And to me a big thing is the difference between creationism and evolution because I'm very confused on the subject. From both my school teaching and my family upbringing so to be a big reason for studying biology is to figure out where I came from and where life came from. And then the purpose of us being there. But that's a different question, that's a sociological question.

B: Right. Forgetting about evolution for the time being and sort of thinking oh, say photosynthesis, now what's the purpose as to why we want to study photosynthesis?

Paul: Well, it give us ideas on how life is like, what happens inside our bodies and inside other organisms on the earth. And it gives us clues on just how we, how we function and it's just the way I see it is, it's to study that is looking for ways we're similar to other plants and the way our body functions. And just to know more about like.

B: Alright. Now when we go ahead and study, say photosynthesis, what is it that we are gaining? What are we picking up?

Paul: Well, picking up knowledge of the photosynthesis function.

B: Can you give an example of knowledge about photosynthesis?

Paul: Well knowing that, well knowing the theory of fluorescence in the chlorophyll molecule. It's easy to see how sunlight or light itself is so beneficial. Like how, why it is needed to a plant.

B: Alright now with that theory of fluorescence, once we have that theory what do we do with it as biologists?

Paul: Well you apply it to photosynthesis, to what goes on in photosynthesis. My problem is that I took physics as well as biology so I learned about photosynthesis... [end of tape]

B: Now you said you were reading the Wu Li Masters and that's making you question whether there is absolute truth. And in the science classes that you have had, has the science been presented so that it was absolute truth.

Paul: A lot of it is. I find especially in chemistry, I don't know so much about biology but in chemistry they seem to tell you something one year and they don't, in at least two of my classes, they didn't question it. But in the next year they seem to change the theory and go farther with it. But in my Chemistry 20 class with Mr. Smith he's very much into ways of knowing and different aspects of a theory and he would quite often say this is what we are teaching you now but later on you'll find out it is a lie, or it is not the whole truth, there's a lot of exceptions and so ever since that class I always question what's being said. Like in sciences I don't think there's any such thing as an absolute truth, ya. Or there's, there always seems to be some exception to a rule. So I don't know I think it helps a lot when you question that. You don't accept everything on blind faith.

B: So, what you're saying that what Mr. Smith taught you is very important because it caused you to change your outlook on science?

Paul: Yes I think it was very important. A lot of people don't like Mr. Smith's teaching methods because there are questions, he questions things, the book says they're true and he talks more about theories and lets you do the work on your own. But to me I think that's an important thing not only in sciences but in anything because it show you that there are different people and you can't be totally closed minded.

B: You said some people don't like Smith's teaching methods because it goes against the book. Now why do you think that would be?

Paul: Well because, well for one thing he talks a lot. He quite often goes off track, but it isn't really. He relates what we're learning in the book with what's happening in Alberta, the world. The ethylene plants for instance. When we were learning organic chemistry he would sort of spend about half a period talking about the process of ethyl, the, that happens in the ethylene plants and he doesn't leave you a lot of time in class to do work. So a lot of people find it frustrating because they like to be spoon fed. So in an essence Mr. Smith is a teacher who is best for somebody who is very inquisitive and likes to learn on what's beyond what's in the curriculum.

B: And what's beyond in the the text?

Paul: Um, huh.

B: Now, something else you said was scientists, in our case we're talking about biology, should not be closed-minded. And do you think that is an attribute that most biologists would have?

Paul: I don't know if they would have.

B: Should they have?

Paul: But they should, ya.

B: Why do you think that?

Paul: Because it is changing all the time. There's always new theories coming up. And if you're, say if you're of an old school of thinking it may be hard to accept. But you should be willing to listen to it and form you're own opinions on it. Because, I think it's really important not to look straight ahead. You have to see the whole picture as it applies to everything. Which goes back to that fluorescence thing, when I learned it in physics I had not an idea that it had anything to do with biology. And then they teach it in biology and it sort of opens up a new light. It sort of clears away some of the cobwebs and things.

B: You talked about biologists being open-minded and having to accept a new theory, how do they accept a new theory? On what basis would you accept a new theory?

Paul: I'd accept a new theory if I could understand if. For one thing, it would have to be simple enough for me, myself to understand. Or for somebody of more schooling to understand. It would have to explain things that have been questioned. it would have to give explanations to ah, if it was replacing an old theory it would have to do as well as the old theory and go farther than the old theory. And replace some of the question that the old had with new answers or even more questions.

B: It has to explain all the old theory?

Paul: Well,...

B: Does it or not?

Paul: It should. I would think, ya.

B: You would think and then it has to go beyond that.

Paul: For me to accept it anyway. Because if you're set in one pattern of thinking and then another one comes out it just explains things that have already been explained I think it would be hard to accept.

B: Just let me jot down a couple of thing here, before they leave. What about if you have an old theory and the new theory only explains part of the old theory, part of the material that was covered by the old theory.

Paul: Ya.

B: Alright, and then this new theory also explains other new observations. Would you accept the new theory on that basis?

Paul: I'd have to go through it, I think. Ya, I think I probably would. Ya, I think so. I would. I'm just trying to think in terms of somebody that has thought the same way for twenty years or something. Say an old scientist who has just come upon this new theory. Which happened a lot in the 20th century with Einsteins' equation and stuff like that. And I think it would be very hard to change my pattern of thinking. But myself, if it did explain part of the old theory and new parts as well, ya I would accept it as long as it sounded reasonable.

B: Do you know where you've picked up these ideas? Any idea?

Paul: I haven't read a lot of that Wu Li Masters thing but I have read some of it and it, just some of the ideas that I get from with inside the readings and just what's implied sort of. As well as Mr. Smith's course. As well as my dad.

B: How has your dad influenced you?

Paul: He's always telling me to be open-minded and not to judge people or ideas, to take a look at a portion in relation to the whole, not in itself. Just, there's probably a lot more things I've picked it up from but they're just sort of hidden.

B: What does your father do for a living?

Paul: He's, he used to work for the city in the town planning department and now he's a consultant. He works for developing firms and things like that.

B: I was wondering whether or not he was a scientist the way you were talking. He's not? O.K. In the narrow sense of the word, a biologist, chemist or physicist or something like that.

Paul: No, he is not.

B: O.K., now another point that come to my mind was that what if you had an old theory that explained something very well but you came across a new theory that does it, that explains the same material in very eloquent way. It does it beautifully. It may be more complicated, it may be let's see, perhaps a little more difficult to understand but it explains it elegantly. Do you know what I'm asking here?

Paul: Well, yes. Sort of it fills in all the cracks sort of thing.

B: Alright, would you reject the old theory and accept this new elegant theory? Or would you take both of them, or would you take just the elegant theory?

Paul: I think I'd have to keep both of them. Because it's hard to say. I think that, ya. I think that both of them would still have, I would still keep both of them in mind, because I just, I don't know why. I just,

B: You just have a feeling?

Paul: Ya.

B: Do you think scientists operate on feeling very often?

Paul: They might. I'd say hunches are a big part of feeling and I'm sure that scientists go on hunches a lot. Ya, I think they probably do. I think they're probably important. Maybe not, when you think of the P.R. view that you get from the media of a scientist. They seem like such cut and dried people. And the sort of, their work is so methodical it wouldn't have room for feelings but I think you'd have to have feelings. They'd have to be there for you to make hunches. To state opinions especially and just to um, accepting a theory you'd have to go on your former education and how you felt about a certain theory before you accepted it.

B: O.K. your description of a scientist there, of somebody who has feelings, that go on hunches and these kinds of things, is that the kind of image that you've seen in your textbooks of scientists?

Paul: Not really.

B: Why do you say not really?

Paul: Well, in the textbooks and different things you get pictures of scientists, well they're just history. And they're portrayed in sort of just an objective point of view. And it's hard to tell what they were really like.

B: It sounds like our time is just about up, thank you.

APPENDIX G

INTERPRETATIONS OF STUDENTS' INFORMAL DISCUSSIONS

STUDENTS EXHIBITING A MODIFIED BACONIAN IMAGE OF BIOLOGY

1. DEBBIE

The view of school biology that is presented by Debbie is based on a logical analysis of controlled experiments that are suggested by hypotheses or theories. This conclusion is based on the following comments:

B: ... Now can you tell me, in terms of biology, what a theory is?

Debbie: Something that can be proved, something that someone, a scientist, has an idea why something occurs. Something that can be proved or disproved at any given time. It is not right or not wrong, um,...

B: O.K. now you've said that, um it is something that can be proved. How would you go about proving a theory?

Debbie: Through several experiments. Um, going through factors that could determine change in the theory. Um, different variables that you could isolate among this or that.

B: ... What do you do when you have done all those extra experiments? What does that do to prove the original theory [van Helmont's]?

Debbie: Look at the um, um, the different things that have happened and try to associate the different things that have happened in both, um in both tests. And try to associate one to the other. Try to see a link somewhere through those different tests.

According to her view biological experiments involve a standardized series of steps. Implied within this view is the image that a biologist advances a hypothesis on the basis of personal observations which is tested by controlled experiments. The degree to which the results verify the hypothesis determines whether it is rejected, modified or accepted as a working statement for future experiments. Additional experiments are conducted which test variations of the hypothesis and upon verification, a theory is formulated which explains observed relationships. A similar research program is developed to test a theory and upon verification of the theory, a law is proposed.

When Debbie was questioned about her perception of biological methods involving a series of sequential steps she indicated that the method results in knowledge. In her words "knowledge is the understanding of why something occurs, or your views of what something is and it can occur throughout the process." There is a tone to her words that suggests the experimental process forms a foundation on which biological knowledge is built. The comment "It's almost like a ladder. Each theory thoughout the years just added on and added on until ...", illustrates this idea. In addition her comment also points to the idea that knowledge gradually accumulates. Associated with her view of knowledge formation is the idea of certainty. According to her conception, knowledge that results from the early stages of the scientific method is less certain than knowledge obtained from later stages. For example, information obtained from a verified hypothesis would not be considered as certain as information from a verified law. It is as if the scientific method is viewed as a way of discovering and evaluating knowledge. The discovery of knowledge is a result of applying the method, while the certainty of such knowledge is determined by the stage at which the knowledge was discovered.

Debbie's view of biology perceives the scientific method as a system which allows biologists to interpret nature and obtain knowledge. At times her conception of the system is complex. For example, partially verified theories are not abandoned but they are not necessarily accepted as working theories by the majority of biologists. Working theories have the characteristics of simplicity, depth and explanatory power. The inclusion of these characteristics in Debbie's conception of biology appears to be the result of instruction in a previous science class. This conclusion is based on conversations with other students who identified the identical characteristics and indicated they learned them in a previous science class. Debbie supported this conclusion but she was unable to specify the course. By including these characteristics in her view she is implying that the scientific process results in multiple theories for a single phenomena. Through the acceptance and rejection of theories biology is seen as gradually moving closer to an accurate interpretation of nature. But Debbie's interpretation of biology includes a provision that achieving such a goal is impossible because "nature is constantly changing."

The following exchange illustrates the idea that it is impossible to achieve a complete understanding of biology.

B: Alright. Now, I said something about a true theory and you've indicated that you can get to a true theory.

Debbie: No.

B: No, you can't?

Debbie: I think that there's always a chance of disproving a theory.

B: So that if you have a theory, um it may be right and it may be wrong but you, you'll never be able to say which it is?

Debbie: Right. You'll think, you'll hope that it will be right but you never know. A hundred years down the road someone may come along with new ideas and disprove your theory. Such as van Helmont's and other ones we've looked at today have been added to and proved or disproved through advances in science.

The meaning Debbie's view of school biology has for biological knowledge is that her perception involves accepting knowledge claims on the basis of the amount of evidence that is available to support them. To her, "the actual knowledge is there, it is just waiting to be discovered or described." Consequently biologists attempt to determine relationships that exist among pieces of knowledge that are known with the greatest certainty and through this process obtain an understanding, or image, of nature. If subsequent experimentation demonstrates that one area of biological knowledge is incorrect that area of the image is removed and either replaced or left blank. It appears her understanding of biology is a mosaic with certain parts in focus, other parts out of focus and additional parts missing.

Some implications of this image are, biological knowledge may one day be almost complete. This has meaning because certain facts of knowledge are accepted as true and they will not change. This is not saying that mankind will ever gain a total picture or understanding of biology; it is just saying that some observations have been made so many times that we can accept them as being true.

2. NORM

According to Norm's conception, the study of biology is accomplished by using the scientific method. A biologist begins the process by collecting available data, forming a hypothesis and conducting a series of controlled experiments to test the hypothesis. If the results of the experiments verify the original statement it is considered proven. The view that proven statements make up biological knowledge is illustrated in the following extract.

B: Alright. Now, when a biologist sits down to do an experiment how does he go about doing it?

Norm: Well he starts off with a hypothesis. Tries to get some facts, by experiments. Biology um, well it deals primarily with experiments, eh? The facts that

B: Um, huh.

Norm: you do ... You have to find facts. They really aren't presented to you. For us, we have a book with the facts. Scientists dealing with biology and botanists, for instance, dealing with a new area in plants, he wouldn't have any. He would have to find his own facts. So by experimentation.

From the discussion with Norm it is evident that he sees the scientific method as a series of steps which verify hypotheses. Once a hypothesis is verified the information is considered part of knowledge. A similar pattern is used to verify theories and laws. An important aspect of hypotheses, theories and laws is that they are sequentially developed and they progressively yield more reliable knowledge. The comment "for us, we have a book with facts" indicates that the scientific method is a source of reliable knowledge and once it is verified it is recorded as fact. The purpose of recording such facts is to maintain a knowledge base so that subsequent work in biology has a foundation.

Norm's view of biological knowledge being made of stable facts is shown in the following excerpt.

B: Alright, so what is a biological fact? We'll start... Can you give me an example of one? Of a biological fact?

Norm: O.K. I'll use plants again. Gases moving in and out of the plant by way of the stomata. And they're controlled by guard cells. And that's a fact.

B: So that would be a fact. Now why is that considered a biological fact?

Norm: Because it's been proven by experiment. By visual experiment. And they've seen stomata open and close.

The phrasing of the statement "and that's a fact" as well as the emphatic tone of voice indicates that Norm unquestionably accepts, as true, the explanation of how gases move in and out a leaf. The acceptance of such facts, as knowledge, is based on inductive logic being seen as a valid way of deriving knowledge claims. Norm uses induction as the basis for believing stomata control the movement of gases in plants. It seems the premises of his argument are based on personal observation as well as the teacher's verbal description of the movement of gases through the stomata. Once he is provided with this information he inductively concludes the expansion and contraction of guard cells control the movement of gases. The conclusion is interpreted as factual knowledge. Within this thought pattern are at least four implications. The first implication is that induction results in valid knowledge claims. A second implication is that personal observation is considered a reliable method of obtaining data. A third implication is that sensory experience is more reliable than thought. A fourth implication is that the combination of personal observation, the scientific method and induction result in certain knowledge. It is suggested that these factors influence Norm's view of biological knowledge.

To Norm biological knowledge is seen in an objective manner. He accepts a direct relationship between what exists in nature and empirically verified statements. If the statements are verified repeatedly they are considered reliable and they are viewed as knowledge. Facts that have been verified over a long period are not expected to change. In Norm's words "facts that can be observed by experiment are most likely not to change." For example, the observation that a chlorophyll molecule has a magnesium atom as the central structure and that atom determines the arrangement of the other atoms, will not change in the future. This stable knowledge forms a foundation on which future biological knowledge is built. Associated with the image of objective knowledge is the impression that biologist discover, or come across, knowledge rather than creating it. Knowledge is not something that is agreed upon by biologists. They work through the scientific method and whatever is discovered is reported as knowledge.

3. PAT

One message that a discussion with Pat revealed immediately is found in this exchage:

B: Now can you tell me how biologists go about performing an experiment?

Pat: How they go about it? First of all they have to have a problem and ah, I guess knowing the experience they have to the problem, they look at procedures, perform the experiment and look at the conclusions.

B: So, how do they come across this problem? How do they get a problem?

Pat: Some unanswered question. Some unknown.

B: And, you don't know... For example, if you were going to generate a problem how would you go about doing it?

Pat: Generate a problem? I'd probably look for something that wasn't proven. Just go from there. See what things I could use in the experimental process and that kind of stuff.

B: And do you, do you have to go through a certain series of steps? And ah

Pat: Just like we're doing today. You go through a series of things and then come up with your conclusions and observations.

B: Alright, and what happens? You say you go through a series of steps. Can you skip any of those steps?

Pat: No.

B: What will happen if you do?

Pat: You results wouldn't be correct.

B: Why not?

Pat: That's why, they wouldn't be appropriate. They wouldn't be accurate to what your trying to find out, eh? If the step was important it wouldn't be in there in the first place. So it must be done in a certain order and it has to be done to get the proper conclusions. The conclusions that you're looking for.

B: So that if you and I were doing the same experiment, alright?, and you decide that, um, you're going to miss a step and I decide to include that step [

Pat: [The results would be different.

B: You're ... Automatically change the results?

Pat: I think so.

B: You would think so? Now, maybe I'm confusing something here. Are you talking about the actual procedure that you're going through the experiment [

Pat: [Uh, huh.

B: or are you talking about that nice neat series of steps that have become known as the scientific method?

Pat: Scientific method.

B: So that, can you just review those for me? What are the steps in the scientific method?

Pat: Problem, hypotheses, ah procedure, observations and conclusion.

From this discussion it can be seen that Pat's view of school biology is firmly based on a structured system that relies on experimentation as a verification method. The process that is involved in experimental verification is the Baconian image of science that is known as the scientific method. To her, studies in biology begin with the biologist accumulating as much information as necessary to conduct the appropriate controlled experiments. The accumulated information is used to formulate an hypothesis and once it has been developed the scientific method is used to arrive at conclusions which either agree or disagree with it. Pat's image of biology is that it is extremely logical with the exception of hypothesis formation. Consider a message that is included in this short exchange:

B: O.K. Now, if I were to make this statement to you, biologists partially make decisions concerning their research on the basis of irrational, unexplainable feelings, what would your reaction to that statement be?

Pat: That's irrational. You can't say irrational, you have to have something to base it on. I suppose that's the hypothesis before beginning the experiment. They don't have anything to base it on. It's just what they've decided and they have to proceed to find out if they're right.

A message that is included is: biology is based on logic and this is why experimental conclusions are true. It appears that Pat sees the scientific method as being logical and thus any experimental results must be considered correct. This conclusion is based on the phrase "they have to proceed to find out if they're right". The wording of the phrase indicates that the scientific method is so precise that biologists know for certain whether experimental results are correct or incorrect. The implied argument is, if the results are correct any conclusions must be considered certain knowledge because the logical process within the scientific method would not indicate that the results were correct when in fact they were incorrect. There is a feeling in Pat's comment that she has accepted a formal logic in the scientific method without being aware of it and then she has unknowingly translated this faith in a process to where any resulting conclusions are accepted as certain knowledge.

Generally her image of biology tends to indicate that if a biologist follows the scientific method and the conclusions support the hypotheses, various facts become known with certainty and they become part of biological knowledge. This image means that individual's senses are the source of observations and when questions arise the scientific method provides a way of answering them. The results that make up the answers are considered true and thus biological knowledge is discovered by controlled experiments. Along with the answering of questions comes the accumulation of knowledge as evidenced by the amount of information we have today compared to early biologists.

An implication of such knowledge accumulation is that biologists are gradually getting closer and closer to an accurate understanding of nature. Since nature is so complex it may be impossible to say that biologists will ever know the complete truth but biology is headed in that direction. An observation that supports this contention is Pat's belief that our present biological knowledge accurately reflects nature and it is not a creation of the human mind.

4. SUSAN

The essence of Susan's conception of school biology appears to be an experimental method which begins with an open-minded search through literature that is associated with the problem being studied. Such an open-minded search is a key element of the method because it provides a framework for the approach to the problem, the method used, the observations that are to be attended to, as well as suggestions for interpreting the results. Once the biologist accumulates sufficient information to act as a framework for the problem he develops a hypothesis aimed at explaining the phenomenon in question. A series of controlled experiments, suggested by the hypothesis, are performed and if the results verify the hypothesis it becomes a scientific explanation. The results are considered as discrete facts, or pieces of knowledge, because they have been observed repeatedly. These non-changing, experimental facts are incorporated in an explanation when a biologist makes a generalizaton about the relationships that exist among the facts. Once an explanation is stated, it, and the facts that contribute to it, becomes part of a permanent body of biological knowledge. The preceding series of steps comprises Susan's conception of biological methodology. Her conception becomes evident throughout the discussion but when she is asked how biological experiments are performed she reveals her view of the scientific method. This point is shown in the following excerpt.

B: ... When you do a biological experiment, what's the first thing you would do?

Susan: You might technically write up, read up and see what we're supposed to do and then I go get the things that are needed for it.

B: O.K., now why would you go ahead and read before doing the experiment?

Susan: So I would know what I'm supposed to be doing and looking for.

B: And how will that help you do that?

Susan: So if I don't know exactly what I'm supposed to do beforehand then I won't know what procedure to follow. I might do it wrong, or I won't know what's exactly involved in what I want to know.

B: Um, huh. Now, when you do that, when you go and read and you get this background information. What does that background information do for you when you are doing the experiment?

Susan: It adds extra knowledge I guess into what I'm looking, what results I should be looking for and what the results mean. Like, it's kind of interesting to know, what it's proving to me. What I'm finding out from it.

According to Susan's conception of biology the experimental method provides both a framework for perfoming experiments and indications of appropriate results. The phrase "what it's proving" shows she extends the meaning attached to the method so that it provides direction in interpreting results.

The foregoing description of the experimental method is for a single experiment. Susan enlarges this method to include subsequent stages in the scientific process. When experimental results do not support the original hypothesis the biologist returns to the hypothesis stage and works through a series of experiments until the original observations, hypothesis and experimental results are in agreement. Assuming agreement among the three aspects of an experiment are achieved and an explanation is produced, a variety of related hypotheses are tested before the biologist moves to the next stage of theory formation.

Gradually, related hypotheses are tested and a number of phenomena are explained. With this accumulation of knowledge a theory is proposed which explains relationships that exist among the phenomena. Once again, controlled experiments are used to test the theory and if the results verify the theory, a law is stated which becomes a permanent part of biological knowledge. With the establishment of a law, biologists are said to understand a certain part of nature because they are able to predict future events.

According to Susan, knowledge consists of facts that are discovered by following the experimental procedure. The following excerpt illustrates her conception of knowledge.

B: Um, huh. Now you've used the word "knowledge." What does the word "knowledge" mean to you?

Susan: Um, I guess it's just extra information that I know, that I can use.

B: Can you give me an example of a piece of knowledge?

Susan: A piece of knowledge is um, knowing the different blood types is knowledge.

Knowledge is treated as if it is made of concrete objects called facts. Such facts exist independently of man and they are considered stable. These characteristics are revealed by comments such as:

Susan: It [knowledge of blood types] was there but it wasn't real knowledge because people didn't know about it. It was a fact but it wasn't a known fact.

B: So you can have facts that are unknown?

Susan: Um, huh.

B: Do facts ever change?

Susan: Um,...

B: For example, will the blood type O ever be discovered that it is incorrect? And say in a thousand years we come back and we no longer have blood type O?

Susan: I don't think that facts... But in that case it might because all the cells of that blood type die out. But I don't think facts really change. ...

From these comments it can be seen that Susan conceives of facts existing in nature and when discovered by the scientific method they are considered part of biological knowledge.

There are several important points involved in Susan's picture of biology. The whole experimental procedure is based on the assumption that the method is correct and any anomalous results are due to human error. In other words, if the results of an experiment do not agree with original observations it is assumed the biologist did not follow the experimental procedure correctly. The possibility that the method is incorrect is not considered.

By putting absolute faith in the method, biological knowledge is seen as consisting of discrete, non-changing facts that gradually accumulate. One result of this accumulation is that present biologists are seen as having more knowledge than biologists in the past. To accumulate knowledge it is essential that biologists are objective, lacking in emotion and coldly logical as far as experiments are concerned. She states these professional characteristics are necessary to avoid biasing experimental results. To her, biologists deal in things that can be observed and measured not with emotional experiences or vague ideas. A biologist works very carefully, gradually discovering one fact after another until a certain phenomenon is explained. Once the phenomenon is explained it fits into a larger category that helps explain other aspects of nature.

Such an image of biology means that the experimental method is independent of the biologist. Knowledge that is discovered through this method is more reliable and has greater explanatory power than knowledge gained from an analysis where opinion is involved. For example, Susan considers knowledge gained from an analysis of a biological experiment more reliable than knowledge gained from an historical analysis.

5. LYNDA

Lynda's image of biology is closely related to the classical method that is known as the Baconian ideal conception of science (Watkins, 1978, p. 23). Her image closely parallels the four characteristics of ideal science: (1) deep truths yield ultimate explanations, (2) facts are known to be true, (3) truths are to be exact, not vague, and (4) connections between statements are to be strictly logical or deductive.

The following comments show Lynda's conception of knowledge and how it is related to truth.

Lynda: Ya. I think knowledge and truth are sort of together in that way. Seeking for knowledge is looking for the truth of why things are what they are and how they came about to be that way. And that in turn will, um, show to the future of what's going to happen in the future by how things change.

When Lynda was asked if facts change she indicated they did not. In her words, "I think facts are what is, so I don't think they can change. Because a fact is what is." Not only does this comment indicate that facts are stable but it also shows that they are thought of in objective terms and they exist outside knowledge. It seems facts describe an element of nature and biologists discover these truth statements through the scientific method. To Lynda, statements that have been verified by the scientific method are considered ultimate explanations and they achieve the characteristic of depth by revealing details of various relationships. These points agree closely with the first three characteristics of the ideal conception of science. Lynda views the use of logic somewhat differently than what is suggested by Watkins. Her view of the use of induction and deduction is indicated in the following comments.

B: O.K., now my question is, um, do biologists work by induction mainly when the're doing experiments and trying to discover these facts and truths about the world?

Lynda: Um, huh.

B: Or do they work by deduction mainly?

Lynda: Both.

B: You say both. Why?

Lynda: Well it can go either way. If some... If they come across something that they don't understand, something very specific, then they can analyze that. And then from that, um find a law that applies not only to that specific example that they found but also to other um, questions that they might have had. And that, but also they could have um, something that they don't understand maybe in a more general sense and then they go to examples to find the answer to that. Instead of looking at something specific and then realizing that it is related to other, ah, um, instances or whatever.

On the basis of her comments it appears that she includes both forms of logic in her notion of biological methodology. In general the transcript shows that she considers Bacon's experimental method as a way of obtaining true facts which make up biological knowledge. These facts are known to be true because of personal observation. An important element in establishing the certainty of these facts is that the hypotheses, from which the facts were derived, were tested by carefully controlled experiments. If the tests were sufficiently rigorous the facts are considered to be certain or true. Once facts are obtained they are used in providing explanations of natural phenomena. According to Lynda both induction and deduction are used to develop explanations of relationships among biological facts.

Lynda's image of biology is that of an ideal science. She indicates that the scientific method yields factual statements which, once verified, are known to be true and as a consequence connections between these statements provide ultimate explanations. Lynda separates the facts of biology and biological knowledge. To her facts are verifed statements but biological knowledge consists of beliefs about those statements. Since she considers facts as being certain it also seems reasonable that she considers knowledge certain. But this is not the case because she has introduced an element of doubt to her conception of knowledge. Doubt enters the image because of an unexplainable feeling that knowledge cannot be certain. A rationale for holding what appears to be an incongruous position was not provided.

The image of knowledge that is implied by Lynda's conception of school biology is based on factual statements verified by the scientific process. A view of this type implies that knowledge is known with degrees of certainty. For example, theoretical statements that have been verified are known with less certainty than an observation that has been observed and experimentally proven many times. According to Lynda, knowledge can be proven by the experimental method as well as the "test of time." When asked what she meant by the "test of time" she stated that if an observation has been made many times this is sufficient reason to believe that the observation will be made in the future and it will not change. In addition the "test of time" is reason to accept the phenomena as being true. To her the experimental method is the more reliable way of establishing knowledge.

In summary, the dominant image of school biology for Lynda is one that includes a systematic method beginning with an open-mind that attempts to gather data that is related to the problem. Next, a series of controlled experiments are performed and the results are considered biological knowledge. The purpose of this process is to produce explanations which allow biologists to make accurate predictions about natural events. In terms of biology her image of knowledge consists of true, factual statements that are discovered by science. These stable facts are accurate reflections of items and processes that exist in nature.

6. TONY

The scientific method as proposed by Bacon forms the basis of Tony's conception of biology. Tony believes that biologists begin a study by accumulating relevant data from all sources and on the basis of this data develop a hypothesis. Following that, controlled experiments are conducted to test the hypothesis and if the results verify it, the original statement is considered part of scientific knowledge. By repeatedly verifying the original observation a theory can be formulated and if it is verified it then acquires the status of a scientific law. Once again key experiments are needed to test the law and upon verification the law becomes part of biological knowledge that is known with certainty.

For Tony the scientific method as outlined is a process that provides confirmation of the biologist's personal observations. This belief involves two important assumptions. The first assumption is a direct relation exists between the biologist's sensory experiences and the natural phenomenon being observed. The second assumption is sensory experiences provide reliable data. It seems Tony is not aware that he is making these two assumptions and that his conception of the scientific method depends on them. There is a realization that biased observations are a possibility but Tony demonstrates an implicit faith in biologists and the method they use. He assumes that the scientific method provides objective results and thus any knowledge that is discovered is also objective and reliable. This belief is demonstrated in this discussion:

Tony: Ya, I think he [a biologist] has a preconceived idea of what's going to happen. And I don't know if that's ... I don't know if that's going to affect the results that much.

B: So, O.K. go ahead. Now you talked about objectivity, and ah, the opposite of that is subjectivity. Now, if you have indicated that biologists are subjective, that it can influence the data, therefore influence the results, influence the conclusions et cetera. What does that do to biological knowledge? What we call biological knowledge?

Tony: It would hold back the progress made in that field. But I don't think it happens in reality to a great degree because you have so many scientists working on this project that they'd overlook something.

B: And you think they are very objective. That they don't ...

Tony: Collectively they would be I think. Because, say one guy doing it and he might not be as objective as say you had ten, ten people working on the same thing. As they'd all see it and they all wouldn't write it off.

The unquestioned assumptions provide the basis for Tony's faith in biologists and the scientific method. This faith is extended to where the experimental results and conclusions are perceived as certain knowledge. The statement "it would hold back the progress made in that field" demonstrates that objective knowledge is interpreted as being certain, reliable and it provides a foundation for knowledge from future experiments. Contained within this statement are the implications that subjective knowledge is not certain, it is not reliable and thus future knowledge should not be based on it. These implications indicate that knowledge gained through the scientific method is considered more reliable than knowledge gained through intuition, religious belief or interpretations of historical events.

The central feature of reliable knowledge appears to be whether events can be observed and measured by experimental means.

Theoretical concerns are rejected because they introduce elements of subjectivity to knowledge thus making it unreliable. Scientific knowledge is true only as long as it agrees with personally observable fact. Such observation may be indirect because of the necessity of complex equipment but it is accepted providing a scientifically logical explanation is available.

Tony's view of biological knowledge is that the scientific method allows biologists to uncover facts that exist in nature. These facts are true and unchanging and providing biologists have been sufficiently clever in designing controlled experiments our understanding reflects perfectly what is in nature. If there is an error or discrepancy between nature and what we call biological knowledge it is because controlled experiments have not been developed to reveal the differences. On this basis biological knowledge is seen as an object that man studies but he has not created it.

7. JIM

Jim's view of school biology is based on the Baconian image of science. This is demonstrated when he was asked:

B: ... How do you think biologists go about performing an experiment?

Jim: O.K. First they ... They first have to come up with a problem. First they take the problem and they analyze it and try to plan out the best way to go about to solve the problem. So they analyze the question first. And after they've analyzed it and come up with the problem and how they're going to go about solving it, they propose a hypothesis which will try to project how the end result will come about. And they may not be right or wrong. It's just an idea of how it may come about. And then they go about the experiment in a very critical manner to make sure that everything they do is correct. And if they're not sure of the results they do an experiment three to four or five hundred times so they are confirmed that their results of the first time or the fifth, or the tenth time are exact.

This excerpt illustrates Jim's conception of school biology is closely associated with the Baconian image. In Jim's view it is apparent that a biologist follows the steps of the scientific method from open data collection to verified statements. Once a series of controlled experiments have been performed and the results are verified the information is considered biological knowledge.

The language in this excerpt indicates that a primary concern of the scientific method is to solve problems so that a correct answer is obtained. This is demonstrated by phrases such as, "try to plan out the best way to go about to solve the problem" and "they propose a hypothesis which will try to project how the end result will come about." The phrasing indicates that biology is seen as a system in which a method is applied to obtain practical answers. This view of biology is further reinforced when Jim states:

Jim: Science is just knowledge. Knowledge and it's applied, how it's applied. Like Newton, he applied his knowledge and worked at it so that he came up with certain laws. That's through experimentation and using these laws we're able to learn more knowledge.

His pragmatic view of biology influences how biological knowledge is perceived. This is shown when he was asked to give examples of what he considered knowledge:

Jim: Alright. Well from class I know what carbohydrates were, what proteins were and how they're used in your body. Like the human body.

B: Um, huh.

Jim: That to me is very important because I'd like to know what's happening inside myself.

The response to the question shows that facts are termed knowledge. An important aspect of such knowledge is that it is immediately useful. In Jim's words "facts are not useful unless they can be applied to help solve or give new insight to old or rigid fields. The combination of facts being interpreted as knowledge and the implication that information has to have immediate utility indicates that biology is viewed in a technical way. By attributing technical characteristics to biology it is being perceived in a particular way. A technical view ignores sociological, philosophical and psychological aspects which influence the development of the science and any knowledge associated with it. For example, the elements of creativity and curiosity are neglected in a technical view because the emphasis shifts to solving problems. According to Jim "a technical view, on its own, does lead one to ignore elements such as creativity and curiosity" but ignoring a technical viewpoint is just as serious. He states a technical view is necessary to obtain as complete a picture as possible and when it is ignored "bias by omission" occurs. Apparently Jim is aware of human elements in biology but they are down-played and his conception is best described as technological.

Once the focus of biology has shifted to solving problems there is a corresponding shift in what is termed knowledge, an acceptable methodology, and the purpose of biology. It appears Jim considers the purpose of biology to be gaining as much factual information as possible so that a solution is found for practical problems. The purpose then dictates that a methodical approach be applied to controlled experiments thus efficiently producing answers. Consequently knowledge is seen as factual statements that are verified by experimentation. The source, or initiating point of such knowledge is a problem that is affecting society. It is the researcher's opinion that part of the faith that Jim is displaying in the scientific method is due to the misrepresentation of the history of biology. Biological history is frequently reported as a sequence of unqualified successes in which one brilliant scientist after another established answers to significant problems. One aspect that is ignored in this imagined unbroken chain of advances is the vast body of material that was accepted as scientific in its day but no longer is it regarded as such. There is a lack of appreciation of unsuccessful experimentation and theorizing about questions that were judged significant at the time. It is the researcher's contention that Jim is not aware of experimental and theoretical failures thus he associates biology with an ability to solve any problem, providing sufficient time, effort and material are available.

A technical view also prevents biological knowledge as being seen as something that evolves by critical selection. A technical view gives a sense that the problem and methodology are logically structured so that resulting knowledge is consistently validated by the community of scientists. This image is opposite one where biologists report conjectures, unreproducible observations or erroneous results that are not validated by subsequent work. The imperfect image of biological methodologies argues for knowledge by consenus. This means that biologists retain what is accepted as knowledge when they are fully convinced it is validated. Thus with the imperfect view of knowledge formation, there is a selection process involved but with a technical view knowledge is predetermined.

INTERPRETATIONS OF STUDENTS EXHIBITING A MODIFIED POSITIVISTIC IMAGE OF BIOLOGY

1. LAWSON

A dominate feature in Lawson's conception of school biology is the reliance upon controlled experiments to yield scientific statements about observations. Providing human error is avoided when experiments are performed the results are accurate reflections of nature and thus conclusions allow biologists to explain a process or relationship that exists in the natural world. The dependence of biology on controlled experiments became evident when Lawson was asked:

B: ... If you were a biologist how would you go about doing an experiment? What would you do?

Lawson: Well you have to analyze what you are doing and then just take the first logical step.

Upon further questioning "the first logical step" consisted of gathering as much background information as possible. Such information comes from observations, past experience or reading accounts of previously performed experiments. The conception of biological methodology is consistent with the classical method that is termed "the scientific method." When asked where Lawson received the idea that biologists follow this method he replied:

Lawson: Just going through school. Biology, O.K., in each biology grade, like last year we did Mendel and he was just lucky in his experiments that he picked peas with each factor was on one chromosome. So he was just lucky. And ah, each course we take there is always someone who is sort of special and Mendeleev in chemistry.

Within his conception of school biology is an indication that nature is not capricious and methods employed by biologists are subject to interpretation and inspiration. As a consequence conclusions are not necessarily true. When confronted with anomalous results of identical experiments Lawson's immediate reaction was to attribute the difference to human error and defend the inherent logic of controlled experimentation. In discussing this point with Lawson he stated that "individual abilities and interpretation are part of human error" thus he is suggesting anomalies are part of biology but he did not question the logic of empiricism.

Another feature of his image of biology is that information is gained through the senses while performing experiments. In addition there is a belief that it is possible to be objective so that any inferences made, provide true explanations of nature. Despite the recognition that biologists are subjective about the design of an experiment or, the interpretation of results these factors are implicitly discounted as affecting conclusions. These points demonstrate an inherent faith that the scientific method yields facts which are considered knowledge.

Associated with Lawson's conception of school biology is the belief that sensory experience is more reliable than thought in both initiating hypotheses and determining what are acceptable observations. By accepting the premise that sensory experiences yield reliable data a question arises as to the level on which such experiences must be observed to qualify for inclusion in biology.

There is a sense in the discussion that sensory experiences must be direct. If the experiences are reported by another individual they are still acceptable because they have been directly observed. An important point to make is the student separates direct and indirect personal knowledge. Direct observation yields knowledge, while reported observations require inferences to be made thus such knowledge is considered indirect. Further, indirect personal knowledge is seen as being less reliable because of the possibility of introducing errors when making the required inferences. This view implies direct personal knowledge provides the basis of biological knowledge.

Early biologists are seen as individuals who used their elementary knowledge to develop a simple hypothesis that could be tested by controlled experiments. Gradually information gained from these experiments provided future biologists with more knowledge that could be used in their investigations. Because modern biologists have a large amount of background knowledge they do not employ inspiration to the same degree as early biologists did. This is illustrated in this excerpt.

B: You say that [the use of inspiration] happened in the past. But, um you don't feel that a biologist today would use that kind of logic, if it can be termed logic? Now it may not follow the rules of formal logic as you would learn in [math,

Lawson: [Ah, ya I know.

B: Can you give me a reason why they would not use it? Can you think [of

Lawson: [I guess not. No. The fact that there's just so much more science now. Well sort of like more ways of going about

> doing things and analyzing and ah, electron microscopes and all that. I just thought they're more positive about what they're doing. ...

The preceding excerpt shows modern biological knowledge as a product of a method which relies on previous experimental information. Implied within these statements is the idea that knowledge is cumulative and it is the result of a logical process. In other words, biologists have sufficient information to produce more knowledge and thus they do not have to rely on inspiration if sufficient background information is available. If a modern biologist is performing experiments in an area that lacks background information he relies on inspiration just as the early biologists did. Besides modern knowledge being seen as logical, it is also interpreted as being certain. The statement, "I just thought they're more positive about what they're doing." indicates biology, as a method, yields information that is certain.

It appears the belief in certain knowledge arises from the idea that controlled experimentation provides consistent results which give an accurate reflection of nature. There is a provision built into this conception of knowledge that accounts for anomalous results. Since irregularities are due to human error biologists obtain a representation of the natural world when they perform an experiment and thus conclusions explain processes or relationships that are perceived to exist in the natural world. This argument indicates an indirect correspondence between nature and our understanding of it.

Expressed within the student's statements is the idea that direct observational experience or experimental evidence is not necessarily more reliable than thought. In Lawson's words "observations and experiments can be just as easily manipulated as [thought] and therefore are no more reliable than thought." A comment of this nature indicates that Lawson believes the formation of biological knowledge depends on methods other than empiricism but he still gives the impression that it is the most reliable. On this basis controlled experiments provide one method of obtaining data which makes up scientific knowledge. Such knowledge consists of what is known by direct personal experience and to a lesser degree by indirect experience. It appears he is using "know" in the weak sense. In other words observations from direct experience become known if he believes the observation, he has good grounds [empirical] on which to base his belief and the belief is established to his satisfaction of being true. There is an unwitting switch of knowing scientific knowledge in the weak sense, to knowing it in the strong sense. Knowing it in the strong sense makes the knowledge certain. In this way scientific knowledge consists of what is known from personal observation.

A claim that can be made about the student's conception of school biology is that he believes the world is knowable through a variety of ways but empiricism is the most reliable. This indicates he is interpreting the physical world to be outside peoples' minds and consequently independent of their minds. His view implies that direct personal observations are partially mediated by culture and thus such observations are accurate reflections of nature.

With the existence of a close relationship between observations and empirical experiments biological knowledge is seen as accumulating and the greater the number of times an observation is made, the more certain the knowledge becomes. This has meaning because Lawson gives the impression that the empirical method provides true, factual information which is certain. Uncertainty is attributed to human error rather than questioning the manner in which empirical knowledge is gained.

2. JUDY

Judy interprets school biology from a practical viewpoint. To her biology is a method that allows mankind to develop explanations of natural phenomena so that it is possible to intervene in the natural world. Her viewpoint is illustrated in the following excerpt.

B: What is the purpose of biology?

Judy: I figure it's pretty well to discover more about what's around us and if something goes wrong you can fix it.

A technical view of biology is presented by Judy. This is evident because the values of certainty, control, precision, predictability and efficiency are essential to her perception of biology. These values are associated with man being able to determine problems in nature and solving them. The elements of certainty, precision and predictability influence what is considered problem solving knowledge. In the original discussion Judy made a distinction between general and biological knowledge. To her, general knowledge is any information that is gained from experience. This broad conception includes mythological stories as well as specfic directions for the use of a piece of equipment. In other words, general knowledge is not necessarily practical. In the case of biological knowledge practicality is not necessarily essential but it does become important. According to her biological knowledge is "everything we know about biology" and when questioned further she states that it is "facts about nature or ways to gain these facts." Although the criterion of usefullness is not mentioned in her conception of biological knowledge, it becomes evident that utility is an important aspect of such knowledge. This point is displayed when she was asked, why is biology studied?

B: O.K., so I understand. For one thing you're telling me it is important to satisfy our curiosity, right? And another thing [is] to make the world a better place? For the betterment of the world? No?

Judy: In so much, if we understand what's going on, if something goes wrong we can fix it. So

B: Ya.

Judy: that if something in the body goes wrong we know enough about the body that we can do something about it. Rather than do what they were doing a couple hundred years ago and just bleed them or something. Now we know what's going wrong and why it goes wrong chemically and physically. We know what happens and so we can fix it.

On the basis of these observations Judy's conception of biological knowledge involves the element of utility and thus an inference that can be made is knowledge is accepted according to this criterion. An implication of this inference is that information which is judged non-useful is still viewed as knowledge but it is considered of secondary importance. The introduction of a usefullness criterion shows Judy has incorporated a sense of value in her conception of biological knowledge. It appears that utility is most important but values such as control and efficiency also determine the status of knowledge. For instance, knowledge gained from an experiment would be considered of secondary importance if it did not allow a biologist to control a situation.

As conceived, Judy's view of biology is a method that produces applicable and non-applicable knowledge. Included in her view are criteria that are used to evaluate knowledge. By including these features in her conception she is limiting originality in biology. Spontaneity and creativity are partially removed from the research process because the criterion of utility limits the questions that are studied. For example, a basic research question may not be studied because it lacks immediate applicablity. The creative aspect is further limited because a utilitarian goal is to solve practical problems as effectively as possible. Since such problems arise from practical situations, the goal of biology is in effect prespecified. Research directions are influenced because desired outcomes are part of prespecified goals. By prespecifying a goal a desired outcome is either implicitly or explicitly stated and thus particular features of the research process are determined. For instance, the research question, its direction, and the methodology are partially determined by stating a goal. By specifying the beginning and the end of the research process constraints are placed on the process and consequently creativity is limited. Seen in this way Judy's view of biology is interpreted to be a problem solving technique in which the biologist's function is to generate correct answers as efficiently as possible.

A particular conception of biological knowledge is associated with Judy's view of biology being a problem solving technique. To her, biological knowledge is all the "proven facts and ways of gaining these facts." Once a factual statement is accepted the possibility exists to use it as a basis to answer other questions. In this way knowledge is seen as facts plus explanatory relationships that exist among the facts. Since facts and interrelationships are constantly being discovered biological knowledge continually grows. The notion of growth means past knowledge serves as a basis for present knowledge and thus there is a sense of an accumulation of knowledge. Even though Judy argues for the growth of knowledge her idea is not extended to where biology results in ultimate truth. It appears her representation of knowledge involves an element of consensus. She states "knowledge is accepted by consensus but it is not formed by consensus." The statement is interpreted to mean that biological knowledge is discovered through the scientific method but before such a discovery is considered knowledge the scientific community must agree to accept the discovery as knowledge. Such a view means that the possibility of biological knowledge changing in the future is a certainty. In Judy's view what is considered knowledge today will not be considered knowledge in the future.

Judy appears to view biology as a technical process that yields information which is accepted or rejected on a consensual basis. If the information is accepted it is then considered biological knowledge. Despite a technical view, and a constant referal to knowledge as "bits" and "pieces of information" she does not view it in an objective manner. In her conception there is a sense that man has created knowledge and this accounts for her sense of certainty that knowledge changes and there is no such thing as a biological truth. Judy views biology and biological methods as tools with which knowledge is created.

3. KATHY

Kathy's notion of school biology is based on empiricism. There is an implicit faith on her part that conclusions based on the scientific method are true. An assumption is made on the basis of her faith in the method. The assumption is that if the conclusions are true then the statements are proven and consequently information contained within such statements is considered fact. Such facts are then considered biological knowledge.

Although Kathy's view of biology is heavily dependent on an experimental approach, she has modifed the classical empiricist position by incorporating intuition and interpretation into the process. By introducing intuition into hypothesis formation, and interpretation into data analysis, Kathy has included an element of tentativeness in her conception of biology. The empirical position and the idea of tentativeness appear contradictory but Kathy has incorporated them into a single view by using empiricism as the foundation by which biological knowledge is first established and then introducing data from other ways of knowing to the system. The combination of empirically derived facts, plus data from intuition and personal interpretation can then be used to develop hypothetical positions that are tested by empirical means. The introduction of tentative knowledge seems to be in respose to a realization that factors other than controlled experimentation influence knowledge formation. Despite this awareness, she has placed her faith in empiricism and the type of knowledge this method generates. The following extract illustrates the degree of faith Kathy has in the method and its ability to yield knowledge which is accepted as proven and therefore necessarily true.

B: See when you think of it, what does that [the realization that biologists may not be objective] do to all of the scientific knowledge that we have? Where does it place

Kathy: You, you kind of put doubt into it now.

B: And had you any doubt about what was scientifically valid before?

Kathy: No, not usually. I usually take it for granted as being true.

Not only does she have faith in the ability of the system to yield valid and reliable knowledge, but she also has faith that biologists perform experiments and interpret results without affecting the validity or reliability of the resulting knowledge. This explicit faith is demonstrated in the following sequence:

B: Alright, now how do you know that [plants need carbon dioxide] is a fact? And two, how do you know it is a "true" fact?

Kathy: You know because that's what they tell you. And you know because through research that's what the scientists have come up with and they've drawn their conclusions.

B: When you say they tell you, who are they?

Kathy: They, people who you believe to have a higher form of education; to be more knowledgeable.

B: So you're basing this on, ah, in this case Mr. D [the classroom teacher]?

Kathy: Yes.

B: And also the people who have written the textbook?

Kathy: Um, huh.

B: The people that actually did the experiment. In this case um, it was, I guess, Calvin you would have been referring to there. Is that right? Who supposedly discovered the steps that go into the dark reaction.

Kathy: Um, huh.

Since Kathy's conception of school biology is based on the empirical method she tends to conceive of biological knowledge as being statements which can be verified experimentally. It appears she is aware of other ways of knowing but she is hesitant to accord these forms the same status that empiricism receives. Therefore biological knowledge primarily consists of factual statements that are derived from observing nature and testing these observations by controlled experiments.

A conception of biological knowledge of this form means individuals do not create knowledge, they discover it. Therefore facts and relationships exist in nature and biologists uncover these elements of knowledge. The exposure of the elements is accomplished by the use of controlled experiments. Such experiments are necessary beause they provide a check on the validity of the conclusions. Contained within this argument for the establishment of knowledge is the unknowing reliance on the inductive method. Since the implications of induction are unknown to Kathy, it is the researcher's opinion that this is the major reason why complete faith is placed in empirical results.

INTERPRETATIONS OF STUDENTS EXHIBITING A CONCEPTUAL CHANGE VIEW OF BIOLOGY

1. JOEL

The conception of school biology that is evident in Joel's comments involves an empirical approach that is modified to fit with realizations concerning knowledge and how it is formed. Joel views empiricism as a method that yields data about nature but the classical scientific method does not have to be rigidly followed to obtain information. This is evident when Joel indicates that it is possible to perform experiments without necessarily forming an a priori hypothesis.

B: Alright, um, is it possible for you to perform an experiment without a hypothesis? Without forming a hypothesis prior to doing the experiment?

Joel: Ah, ya I guess so. If you're not sure what you're looking for you can. I guess you can. Because if you're not expecting what's going to be the outcome of the experiment then you can. I guess you can. You could have formed a general hypothesis but nothing really specific.

His point is extended to theories and other structuring elements that are a central part in other students' conceptions of empiricism. Joel's view contains a pragmatic element when a biologist is either doing original research or performing verification experiments such as those done in biology classrooms. In the case of original research the biologist may not have any idea as to what results are expected thus experiments are performed without a specific hypothesis. The purpose in this type of situation is to gain background information. In the case of verification experiments the results are so well known that a statement is made about what students are expected to observe thus a hypothesis is not stated prior to the experiment. According to Joel "the hypothesis can be stated after the experiment." This style of thinking was expressed in the following discussion:

B: Alright, for example that little lab that you did in class this morning, did you have a hypothesis prior to doing that?

Joel: Well the teacher told us what to look for before. Experiments are sort of the same thing that he said what we were looking for was the colour separation

B: And so... of the pigments?

Joel: Ya. That's what we expected to happen. He said that before the experiment.

B: And so a hypothesis is a statement of what you expect to happen?

Joel: That's, that's not really of... The hypothesis is just what you're setting out to prove or disprove, the question or statement. So he really didn't state a hypothesis. He just stated what to look for.

B: O.K., so a statement in that sense is different from a hypothesis?

Joel: Ya.

By viewing biological experimentation as a continuum, with original research being one extreme and verification experiments the other extreme, there is an implication that following the scientific method is inappropriate, appropriate or unnecessary. In the case of original research it is inappropriate because insufficient information is available. In the second case where an experiment has sufficient information but the results are not predictable a scientific approach is appropriate. In the third case of verfication experiments the scientific method is unnecessary because the results are predictable.

This observation is interesting because Joel has incorporated a sense of practicality into his view of biology. Thus he is viewing the methods used in biology as being partly created by scientists and partly due to the science.

With the implicit realization that biological methods are partly due to scientists' creativity this means knowledge derived from such research is also influenced by a human element. An indication of this perception is found in a comment made by Joel when he was asked:

B: ... ah, what does that [the changeability of what is termed fact] mean to scientific knowledge?

Joel: All that it means is everything that's said isn't necessarily true, now. You can't prove it otherwise but it's , it's the best explanation we have in something.

This excerpt demonstrates that he recognizes biological knowledge is accepted on faith and it is not a dogmatic assertion of a direct correspondence between natural phenomena and personal observation. When he says "you can't prove it otherwise" he means whatever is currently accepted as fact is accepted as knowledge because it cannot be disproven. Also within the phrase is a realization that a potential exists for changing what is accepted as knowledge. Since Joel incorporates tentativeness and acceptance by individuals into his conception of knowledge this means he views biological knowledge as being influenced by man.

Joel's conception of school biology is largely that of an empirical approach that is modified by a variety of factors. It appears one factor is recent teachings that present science as one way of knowing. The following extract illustrates this point.

B: Is the information you have received over your twelve years of schooling in science classes, has it been presented in that way? That science is something that constantly changes? Even though we're calling it fact today it may not really be true?

Joel: Ya, in chemistry we know that it is said the theory must be simple and it must be adaptable to change and a couple of other points.

B: Which chemistry class was this?

Joel: Chemistry 20/30.

When questioned further, Joel indicated the teacher included specific material on the nature of science and different ways of knowing and it appears this material has influenced his view of the development of knowledge.

2. PAUL

Paul's conception of school biology appears to involve a conceptual change view. There is an indication that experimentation provides the basis for biological knowledge but such knowledge is subject to interpretation. The knowledge basis seems to be founded on the belief that experimentation provides a degree of evidence which is tangible and, therefore, more acceptable than other forms of evidence. This view is evident in comments such as this:

> Paul: I'd have to go through it [the basis on which a new theory is accepted], I think. Ya, I think I probably would. Ya, I think so. I would. I'm just trying to think in terms of somebody that has thought the same way for twenty years or something. Say an old scientist who has just come upon this new theory. Which happened a lot in the twentieth century, with Einstein's equation and stuff like that. And I think it would be very hard to change my pattern of thinking. But myself, I think myself, if it did explain part of the old theory and new parts as well, ya I would accept it. As long as it sounded reasonable.

The sentence "as long as it sounded reasonable" demonstrates that factors other than experimental verification affect what is accepted as biological knowledge. In this case a non-rational factor of apparent reasonableness is used to help make the decision. Comments about "hunches" and "feelings" indicate an image of biology that incorporates subjective elements. Another indication that his view is a subjective one, is that he states experimentation introduces restrictions to what is considered knowledge. The implication is that the scientific method channels individual's thoughts and thus the method influences what is finally accepted as knowledge. The following exerpt illustrates the idea that subjective elements are involved in knowledge formation.

B: Do you think scientists operate on feelings very often?

Paul: They might. I'd say hunches are a big part of feeling.

B: Oh, yes.

Paul: And I'm sure that scientists go on hunches a lot. Ya, I think they probably do. I think they're probably important. Maybe not, when you think of the P.R. view, that you get from the media, of a scientist they seem like such cut and dried people. And they sort of, their work is so methodical it wouldn't have room for feelings. But I think you'd have to have feelings. They'd have to be there for you to make hunches. To ah, state opinions especially and just to um, accepting a theory you'd have to go on your former education and how you felt about a certain theory before you accepted it.

Contained within Paul's view of school biology is the image that biology is engaged in for practical and idealistic reasons. To him, the purpose of biology is to "gain practical knowledge, it is a very practical science." He does not make a distinct separation between curiosity and practicality in terms of basic and applied research. He states that biology answers practical questions and it also satisfies man's curosity about the natural world. When asked if he considered the practical aspects of biology as being more important than the idealistic ones he said that he could not make a decision as he sees merits in both positions. The knowledge basis for biology is still controlled experiments but the introduction of non-rationalness to the acceptance and rejection of knowledge indicates that Paul has incorporated an element of relativism in his conception of biology.

The inclusion of subjective elements in Paul's conception of biology is evidence that he considers biological knowledge to be interpretable. An element of interpretation in biological knowledge is contrary to material presented in science classes and textbooks. The following excerpt shows that in Paul's view material in science classrooms is often presented as dogma.

B: Now, you said you were reading the Wu Li Masters and that's making you question whether there is absolute truth. And in the science classes that you have had, has the science been presented so that it was absolute truth?

Paul: Um, a lot of it is. I find especially in chemistry, I don't know so much about biology. But in chemistry they seem to tell you something one year and they don't, in at least two of my classes, they didn't question it. But in the next year they seem to change the theory and go farther with it.

The fact that a dogmatic stance is recognized in both classroom and textbook presentations shows a questioning attitude on Paul's part. It also introduces the possibility that biological knowledge is being viewed as subject to interpretation. The model of biology that is being projected is one that emphasizes consensual knowledge which is not necessarily true in every detail. The possibility exists that knowledge may contain large conceptual errors. This relativistic model is based on common sense, a realistic view of the world and how individuals function within it. The common sense view is then extended to biologists and how they are perceived as functioning within a scientific perspective. The argument seems to involve the rationale that man perceives a coherent world and biologists are expected to perceive the world in a similar fashion. Since non-scientists use a variety of methods to determine the acceptability of information, scientists are also expected to make use of similar methods. For example, individuals use both logic and intuitive feelings to make decisions, thus it is expected biologists also do this. Paul appears to have combined a common sense approach to the world with a questioning attitude to arrive at his conception of biolgical knowledge.

One of the characteristics of knowledge that would be consistent with this view is the idea that knowledge is influenced by factors other than experiments. For example, politics, economics and common sense are some factors that Paul identifies as conceivably influencing the direction of research and thus influencing knowledge formation. The awareness that cultural factors are involved means that knowledge is interpreted differently by different people. As a result of interpretation, certainty is removed from knowledge claims. By removing certainty, the idea of absolute truth becomes an impossibility and this raises questions about how biology is taught. Doubt is being consciously introduced to his notion of biological knowledge. Paul prefers to view doubt of this form as a questioning attitude or a form of skepticism. The inclusion of a questioning attitude allows him to be constructively critical of biology and biological knowledge.

3. ALLEN

Allen incorporates a variety of elements into his notion of school biology. The image is one of empiricism that is modified by developments in the philosophy of science. The classical scientific method is central to Allen's image of biology. There is a sense that man's observations of nature are not totally reliable but controlled experiments allow reliable inferences to be made about the information gained. It is on the basis of inferences that facts become accepted as knowledge. To Allen the scientific process of moving from hypotheses, to theories, to laws reveals information which "gradually builds and gathers strength and becomes knowledge."

The reliance on experimentation as a basis for Allen's view of biology is shown in this excerpt:

B: ... Now can you tell me what a theory is to you?

Allen: A theory? It's a, let's see,... It's a statement, it's a statement that makes a prediction, an explanation of course, simple as well.

B: O.K. It has to be simple, it has to make predictions, it also has to explain. Anything else?

Allen: It's derived from experimentation. Um, it has... It's not definite. Ah, there's always possibility for change. In other words, other theories can be derived from it as well.

He limits the derivation of theories to the empirical method which indicates that his primary view of school biology is based on the "classical scientific method". Throughout the discussion, this basic element is evident but other influences from the philosophy of science are observed. For example, there is an implied faith that observational experiences are reliable and they form the basis of experiments. In addition there is a belief in the logic of induction and that hypotheses, theories and laws are confirmed by this form of reasoning. He attributes this belief to the way science is presented in classes. According to his perception of science classes "something was stated and it's assumed other cases apply." The use of induction is suggested in the following comments:

B: Can you give me an example of a scientific fact? A biological fact?

Allen: Um, any science?

B: Yup, it doesn't matter.

Allen: Um, cells have DNA.

B: Now, how is that scientific fact, that cells have DNA, different from the cell theory? Have you talked about the cell theory of Schleiden and Schwann?

Allen: Where cells come from other cells and

B: Yes. Yes.

Allen: Ya.

B: O.K., how is, how is the fact that cells have DNA different from the cell theory?

Allen: Um, knowing just that cells have DNA is just, is just a piece of knowledge rather than the cell theory. It allows us to develop the fact that cells have DNA. Um, it has more evidence for us to branch off into diverse areas.

The statement "it allows us to develop the fact that cells have DNA" indicates that a process is involved in going from a theory to facts which are considered biological knowledge. The process includes controlled experimentation and inductive logic is used to arrive at conclusions which become knowledge.

The foregoing points are part of a logical empiricist's philosophical position but Allen cannot be considered part of this group as his conception of biology includes elements of the conceptual change view. An illustration of the conceptual change view is found in his view of how theories are developed and accepted by biologists.

B: Ah, alright. So that we'll go back to our theories for a minute here. How do biologists accept a theory? On what basis do they accept a theory?

Allen: Um, mass approval.

B: Mass approval?

Allen: Yes, among the scientific community I suppose. Not necessarily in the general population, within the scientific community.

B: Alright.

Allen: Um, if it seems to have some validity, I guess that's why it becomes accepted. If it has potential.

B: When you say potential, what do you mean?

Allen: Such as to ah, to predict others.

B: O.K. potential to make predictions. Any other reasons you can think of why scientist would accept one theory and not another?

Allen: Um, maybe they've proved it wrong. Maybe they've proved another theory to be more correct than another.

B: O.K. and how would they go about doing that?

Allen: Again through experiments.

B: Again through experiments. If they do, um and end up showing that another theory, a conflicting theory, has got problems in a certain area, do you have to reject the whole theory? The theory that's got problems or do you

Allen: It's just altered. It can be altered.

B: You can alter a theory?

Allen: Such as a hypothesis can be altered to make for problems, more exceptions to the case or...

B: That leads me to ask you about what are called ad hoc statements to theories. So, do you understand what it means? O.K., if we have a theory that runs into problems in a certain area, is it permissible for us to add certain statements into that theory in place of those that were there before that gave us the problems? That would be called an ad hoc statement. It means you add them after the fact. So that you're adding statements after the fact.

Allen: Is it permissible?

B: Ya, can you do that and still maintain the theory?

Allen: Well of course the original theory isn't, isn't in the same form. Um, someone had to create the original theory, so I suppose it's permissible for one if he's justified to change.

B: So you feel that, that is something that is permissible. And ah, is it permissible to have a theory and it is not making the predictions we would like but we still maintain through the statements of the theory... Is it permissible to add auxiliary statements? In other words, some additional statements?

Allen: Instead of replacing?

B: Ya.

Allen: Ya.

B: Once again you can do that? Without creating your theory a problem? Will it be the same theory if you add auxiliary statements?

Allen: Well I suppose there has to be a cut off point or the theory starts to encompass too broad a range. Um, I think it can be added to a point.

Allen suggests that theories are developed through experimentation but it is acceptable to use both ad hoc and auxiliary statements to adjust a theory so it maintains its predictive power. He also identifies other characteristics of theories but argues the acceptance of a theory is based on apparent validity as judged by biologists. The inclusion of judging theories by mass approval suggests Allen accepts a relativistic view of the development of biology. The sense of biology being relative is further enhanced by the manner in which hypotheses and theories are rejected. Once again it is a personal judgement of whether the hypothesis or theory has value. If certain aspects are judged as being in error then the theory is not necessarily rejected. Instead the elements of the theory, that are considered of value, are examined and it becomes a matter of personal judgement whether or not the theory is rejected.

The conceptual change view elements of Allen's view of biology influence his perception of biological knowledge. Since empiricism is an important part of his view of biology, knowledge is seen as factual information that is verified by controlled experiments. As a result, knowledge is still seen in an objective manner but the introduction of relativism removes certainty from it. By indicating that hypotheses, theories and laws are accepted and rejected by concensus he recognizes a human influence in knowledge formation. In effect, this removes certainty from biological knowledge because future biologists may accept a totally different view of some aspect of nature and neither the current nor future view could be conclusively disproven. On this basis previous knowledge is not necessarily used as a foundation for current research. It is conceivable that a biologist performs experiments in a research program without knowing or using the knowledge of photosynthesis that was gained by early biologists. As befitting a relativistic view of knowledge Allen indicates under specific circumstances the preceding statement accurately reflects his views but in other cases it does not. He states a "foundation is necessary for knowledge but this may be built on fallacies because knowledge is uncertain." This comment is interpreted to mean a current research program results in inferences that are accepted as knowledge. The use of words such as "foundation" and "built" show he views knowledge as cumulative. In discussing this point, he agreed with the interpretation but he added a provision that the certainty of knowledge is lacking because the possibility exists that the original knowledge claims are fallacious. According to Allen's view both past knowledge and the present consensual view form a framework for the formation of knowledge from biological research.

Allen interprets knowledge to be statements that are proven by the empirical method. To him proven is the equivalent of verification by the scientific method. His view of knowledge also includes relativistic elements because biology is seen as an area of research - that is influenced by individuals and knowledge is what is accepted by the group. Despite his conception of a gradual accumulation of knowledge he still maintains that it is tentative and subject to change. The view of tentative knowledge also conflicts with his belief of the "existence of an absolute truth" in biology.